AIR-TO-GROUND MISSILE CONSTRUCTIVE MODEL DEVELOPMENT AND IMPLEMENTATION IN MODSAF

by

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ABSTRACT

This research explores two major research gaps. First ,this research explores the development and implementation of an improved and more realistic representation of air-to-ground missile behaviors for the constructive simulation, ModSAF. The research sought to develop and test a viable method of replicating missiles while minimizing computational demands. The research required the identification of the performance attributes associated with an air-to-ground missile, the analysis of available seeker technologies, and the development and testing of an implementation algorithm. The new implementation algorithm is the Accumulated Missile Error and Target Action (AMETA) method.

The AMETA algorithm is based on discrete event simulation principles. Critical points along the missile's flight path are used to apply errors that would normally accumulate in the period preceding the point. The magnitude of each accumulated error is determined by simple calculations, random draws and table look-ups. In addition to replicating realistic behaviors and occurrences, the AMETA algorithm is computationally efficient.

Secondly, in addition to implementing the AMETA algorithm, this research sought to represent the Hellfire III missile variants and a helicopter entity capable of launching the missiles. Representation for three Hellfire III variants, Millimeter Wave (MMW), Imaging Infra-Red (IIR) and Laser Detecting and Ranging (Ladar), were

created. This was done by modifying numerous ModSAF libraries and creating computer code that enabled the replication of realistic missile behaviors.

The research evaluated the Hellfire III missile variants through the use of three simulation scenarios. The scenarios consisted of a task force defense, task force attack and a deep attack. A variety of metrics, including Loss Exchange Ratio (LER), were used to assess the Hellfire III variants against one another and to the Longbow Hellfire. The Hellfire III missile variants and Longbow Hellfire were compared using each metric in both moderate and adverse weather conditions. Two comparisons: normalized mean and t test with a 95% confidence interval were used to compare the mean values of the various seeker/weather combinations for each metric.

Several conclusions were drawn by considering the practical and statistical significance of the output data. The results indicate that the Hellfire III variants are superior to the Longbow Hellfire with regards to LER, and target engagement ability. Additionally, the research shows that the Hellfire III Imaging Infra-Red missile is the least desirable of the three seekers when attempting to engage targets with a Hellfire missile in adverse weather. The research also demonstrates that quantifiable errors can be represented in ModSAF through the use of the AMETA algorithm.

To those that believe in truth, honor and justice and have pledged to give their lives in defense of the Constitution of the United States so that the unappreciative masses can enjoy freedom. My sincere hope is that this work can help minimize the number of American soldiers that pay the ultimate price while serving our great nation because only the dead will never see war again.

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This research would not have been possible if not for the dedicated effort of Dr. Michael Proctor, Dr. Ephraim Martin, Dr. Charles Reilly, Jon Williams, Mark Bovankovich, Troy Barnes, Major Steve Brown and Captain Bill Williams. I am deeply indebted to these gentlemen for their hard work and sound advice. They add credence to the quote "success has a thousand fathers, failure is an orphan".

Dr. Proctor identified the inadequacies of ModSAF with regard to accurate representation of air-to-ground precision guided missiles. Dr. Martin used his expert knowledge to identify essential elements of a missiles performance required to develop a realistic model and then validated the constructive model. Dr. Reilly was the inspiration behind the NETMOSA methodology. Jon Williams wrote the computer code and modified the ModSAF libraries required to implement the AMETA algorithm. Without him, the AMETA algorithm would only be theory. Mark Bovankovich provided invaluable insight and analysis of the errors and events that occur in the time period from missile launch and missile impact. Troy Barnes wrote the computer code of the post processor, known as the Reaper, and enabled the analysis of the data. Major Brown served as a sounding board and advisor for the tactics utilized in the construction of the scenarios. Captain Bill Williams shared his many lessons learned from his research and illuminated many potential pitfalls.

I am also deeply indebted to my parents, wife and 19 month-old daughter. My parents possess a work ethic and value system that is uncommon and extremely desirable. They believe in personal responsibility and an obligation of individuals to society. My wife, Michele, has provided immense support and helped with the resolution of numerous problems. My daughter, Lauren, has brightened many days with her unconditional love and helped me get past the periods when the research was not going as I hoped.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF EQUATIONS

CHAPTER 1

INTRODUCTION

1.1 Background

> "War is probably the most inefficient human activity ever devised. Quite apart from the waste of resources which it represents in terms of lives, weaponry expended, and targets destroyed, the actual process of war making involves operations whose success rate can be abysmally low. To put the matter bluntly, most weapons miss their target." (Richardson, 1982)

The use of Precision-Guided Munitions (PGM) is a method to improve the odds of hitting the target. Precision-guided munitions, sometimes called smart weapons, utilize technological advances to increase their effectiveness on the battlefield. Precision Guided Munitions differ from traditional munitions in one fundamental respect. Traditional munitions, once fired, are under the control of the laws of gravity and ballistics. In contrast, precision-guided munitions can correct their course after being fired. Whether guided by their own sensors and computers or by human control, precision-guided munitions transform the statistical foundations of war and with it the calculus of both military and political power (Friedman, 1996).

The era of precision guided weapons began in 1943 with the sinking of the Italian battleship *Roma* as she sailed in the straits of Bonifacio. The *Roma* sank as a result of the impact of two PC 1400X radio-controlled bombs, also called the Fritz X, that were dropped by the Luftwaffe. During the remainder of World War II, nearly eighty ships

were sunken or damaged before the allies developed electronic countermeasures to jam the weapon's guidance link. Not to be outdone, the United States developed the AZON (AZimuth ONly). The AZON was a precision guided weapon controlled by an operator using a joy stick. The AZON was radio controlled but could only maneuver left and right. To assist the operator, the AZON had a flare on its tail so it was identifiable during descent and the operator could provide guidance. Late in the war, the AZON was given the capability to maneuver in both range and azimuth and was renamed the RAZON (Range and AZimuth ONly). The Army Air Corps and Navy used the AZON and RAZON to attack point targets and shipping in the Pacific Theater before the end of the war in 1945. Although these weapons only achieved limited success, the future of precision guided weapons showed promise. However, the United States failed to pursue precision-guided weapons after World War II and was unprepared for the upcoming conflict in Korea, and later, Southeast Asia (Walker, 1987).

The early stages of the conflict in Southeast Asia highlighted a deficiency with the ability of American pilots to destroy targets. This resulted in the expenditure of large quantities of ordnance and repeated attacks on objectives to achieve desired affects. The Vietnamese identified this tactic and arranged their air defense nets in response, which resulted in increased American aircraft losses. The initial American response to the increased loss of aircraft was to modify tactics. They began flying faster and at higher altitudes to remain out of the range of enemy air defense weapons. This resulted in even less effective bombing due to decreased accuracy (Walker, 1987).

The United States began experimenting with laser guided bombs in the mid-1960s in an attempt to reduce the number of aircraft lost in Vietnam while increasing bomb

damage. The first testing of laser guided bombs occurred in April 1966 at the USAF Armament Development and Test Center at Eglin Air Force Base. On May 24, 1968 the first combat launch of a laser-guided bomb was made in Vietnam. By the end of the conflict, the USAF and US Navy had dropped more than 20,000 laser-guided bombs. Targets included bridges, individual vehicles, air defense weapons, power stations, depots, runways, roads and railways. The most famous instance of laser-guided bomb effectiveness was the destruction of the Thanh Hoa road and rail bridge over the Song My River in North Vietnam. Prior to the attack using precision guided weapons, the United States had attacked the bridge numerous times and lost many aircraft. Finally, on 13 May 1972 a single flight of USAF F-4 Phantoms downed the bridge using 2,000 and 3,000 lb. laser-guided bombs (Richardson, 1982).

The interim period between the Vietnam War and Persian Gulf War saw many advances in weapon technology. During the 1980s, the Reagan administration displayed a determination to restore the U.S. military power and to refurbish the country's international prestige and influence. The Reagan administration identified technology as the key to the restoration and launched a comprehensive defense buildup through force modernization programs and long-term research and development projects (Clark and Lilly, 1989). The fruits of the Reagan administration military policy were realized during the Persian Gulf War. In 39 days, the precision bombing of the allied forces so thoroughly smashed the Iraqi military structured and reduced the front line Iraqi soldiers will to fight that the ground campaign only lasted a mere 100 hours. Although a significant portion of the precision guided weapons were launched from airborne platforms, ground based and sea based precision guided weapons were also available and

employed. The utilization of the combined arms and combined service approach had a devastating effect and contributed to the reduction of allied battlefield losses.

1.2 Technology, Weapons and Time

"The impact of technology on warfare is as old as the Iron Age and through history the nature of warfare (and hence the relations between states) has changed-in some cases very dramatically-as a direct result of some new invention and its application to warfare. It is a demonstrable truth that the rate of change of technology has been and seems likely to remain, exponential." (Alford, 1981)

As we look forward and wonder what the future holds, we can assume some tendencies that have held true in the past will continue. In their book "*The Future of War*" George and Meredith Friedman identify eight points of weapon development. Briefly stated, they are:

1. New technology frequently appears less sophisticated than old technology. In the twentieth century, the battleship appeared to be the apex of technology while the aircraft that flew against it seemed flimsy and primitive.
2. Each weapon system has a life cycle.
3. The weapon system reaches its limit of usefulness when the defensive measures necessary for its survival destroy the weapon's cost effectiveness.
4. The army least likely to recognize point 3 is the one that has been most successful.
5. At its high point, just before disaster, the last generation's technology appears invincible.
6. The technologies that succeed in defeating the previous reigning weapon system share one characteristic: a simplification of warfare, returning to the heart of warfare-the relentless offensive.
7. Parasitization is always under way-each weapon becomes senile.
8. A successful military is the one that can constantly overthrow old weapons and doctrine and integrate new ideas and personnel without social upheaval.

In general, George and Meredith Friedman are saying that to remain competitive on the battlefield, a nation must continually strive to equip its soldiers with modern cost-effective weapons. With this in mind, consider the Hellfire missile. Initial research

began in 1970 and the first launch occurred in 1978. Operational testing was completed in 1981 and the first operational Semi-Active Laser (SAL) missiles, the AGM-114A, were delivered to the United States Army in 1985. Six years after the initial fielding, the missiles were employed during the Gulf War and approximately 4000 missiles were fired. Analysis of the missile's effectiveness indicated that the Hellfire system possessed significant shortcomings when utilized against targets with reactive armor. Following the war, upgrades were ordered in 1991. An improved SAL hellfire, the AGM-114K, began service in 1993. If the past is indicative of the future, the AGM-114K will have significant shortcomings by 1999 ("USA: Air to Surface Missiles", *Jane's Air Launched Weapons*, 1997).

America has very good weapon systems at present. However, technology is evolving rapidly and the weapons manufacturing industry must endeavor to apply the technological advances to viable weapon systems. The basic steps of development and acquisition process are: research, requirement formulation, concept evaluation and validation, system prototype development, production and deployment. These steps require 10 to 15 years to complete (Clark, 1989). The time to upgrade existing systems is significantly shorter and relies heavily on the degree of change to be implemented.

1.3 Current Technology

"The effects of technology, manifested in increases in human capabilities, can exhibit unforeseeable scale, multiplicity, power, and even transience. Who can foretell the global consequences, especially the second order synergistic effects of integrated systems, of advanced technologies over the long term." (Clark, 1989)

Sometimes it is unclear whether technology is facilitating new precision-guided weapons or if the desire for more lethal weapons is driving technology. Two things are

certain; neither case is an absolute and precision-guided weapons have progressed to an impressive level of sophistication because of the maturation of the technologies used in their construction. The maturation of technologies occurs because of extensive research and development programs which take infantile concepts, limited in scope due to an incomplete understanding of the potential of the technology and develops the central technology as well as the supporting technologies. It is significant to note that precision guided munitions research and development has the potential of leading advances in integrated circuits, artificial intelligence, composite materials, propulsion, optical information processing, advanced sensors and software. Precision-guided weapon research has the potential of enhancing a nation's overall ability to maintain a technological edge and contributes to the viability of the industrial base (Boyle, 1987)

"A primary requirement of a complete weapons system is that it have some means of detecting a target. In order to accomplish this, the weapons system must be capable of sensing some unique characteristic that differentiates or identifies it as a target. One such characteristic is the energy that is either emitted or reflected by the target. This energy may be in several forms, including electrical, audio, heat or visible light. A characteristic common to all the energy forms listed above is their manner of propagation. That is, they all propagate in the form of traveling waves and as such can be defined and categorized by their frequency and wavelength. It is the function of the sensor system to detect the appropriate energy form and to furnish the information thus obtained to the components of the weapons system." (Frieden, 1985)

Several current missile guidance technologies are the semi-active laser seeker, the Millimeter Wave seeker, the Imaging Infra-Red seeker and the Ladar seeker. Each of these has inherent strengths and weaknesses that are directly related to the electromagnetic

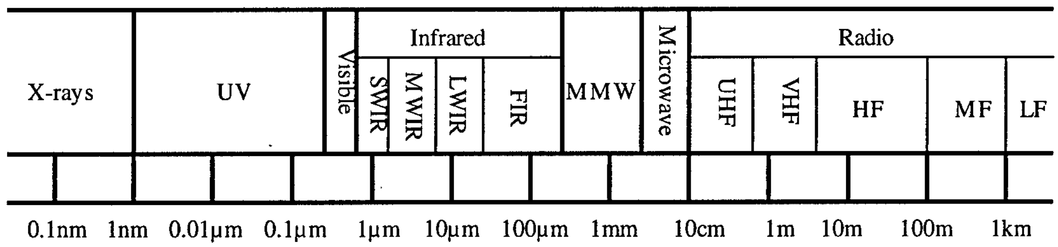

Figure 1. The Electromagnetic Spectrum

spectrum. An important parameter of electromagnetic radiation is wavelength. Wavelength enables the classification of radiation into categories (Dereniak and Boreman, 1996). As a point of reference, visible light occupies a band on the electromagnetic spectrum that includes wavelengths from 0.4 micrometers to 0.76 micrometers (Frieden, 1985). The Infrared band has wavelengths from .77 micrometers to 1 mm. The infrared band is broken down into four regions. The short wave infrared imaging band (SWIR) includes wavelengths from 1.1 to 2.5 micrometers. The mid-wavelength infrared (MWIR) spectral region covers approximately 2.5 to 7.0 micrometers. The long wavelength infrared (LWIR) spectral band covers the region from 7.0 to 15 micrometers and the far infrared region (FIR) covers the spectral band from 15.0 micrometers to 1 millimeter (Holst, 1995). The millimeter wave portion of the electromagnetic spectrum lies between the far infra-red regions and microwave and has wavelengths of 1mm to 10 mm (Alton, 1992).

"Propagation in all parts of the electromagnetic spectrum, ranging from the visible to infrared and radio frequencies, suffers to a degree from absorption of the electromagnetic energy by atmospheric gases such as water, carbon dioxide, oxygen and ozone, and from attenuation by atmospheric aerosols such as haze, fog, clouds and rain" (Sundaram, 1979). This fact renders certain wavelengths unsuitable for use by the guidance systems of military weapon systems as is seen in Figure 2.

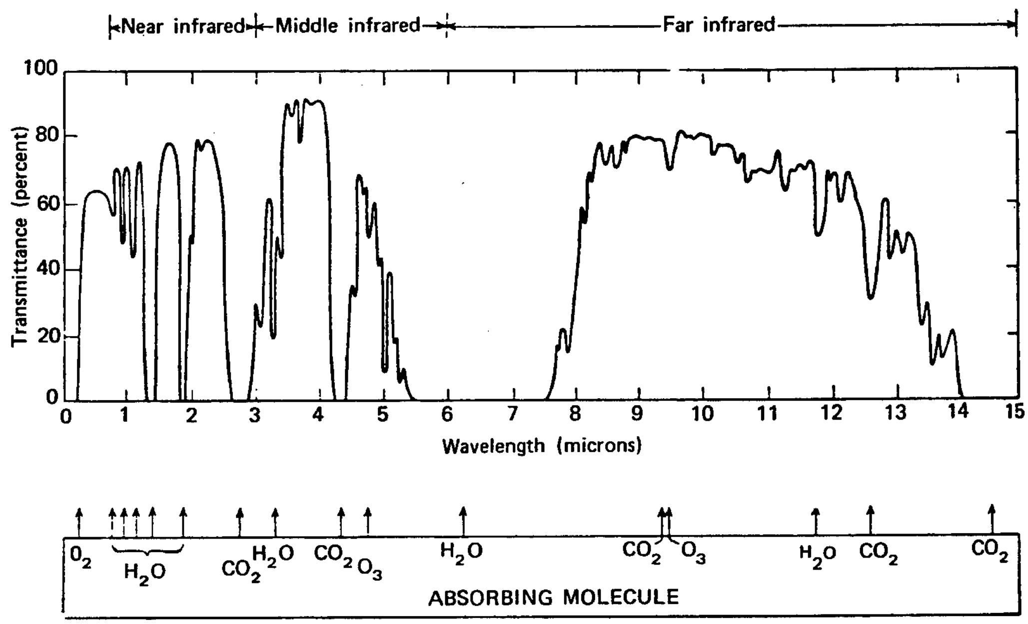

Figure 2. Atmospheric Absorption in the Infrared Band (Adapted from Army Material Command Poster DAAHO1-89-D)

Regions of the electromagnetic spectrum where gaseous absorption is at a minimum and superior propagation exists are referred to as 'atmospheric windows'. The regions of maximum absorption are referred to as the 'absorption bands'. The main millimeter wave windows are 8.5, 3.2, 2.1 and 1.4mm corresponding to frequencies of

35, 94, 140 and 220 GHz. The RF windows (main microwave bands) are 10 and 3 cm (Sundaram, 1979). The two areas of the infrared band that are primarily used are the 3 to 5 micrometer band and the 8 to 12 micrometer band. The 8-12 micrometer band transmission efficiency is generally 70-80% and the 3-5 micrometer band transmission frequency is between 60 to 70%. The 8-12 micrometer band is a more efficient window than the 3-5 micrometer band since it is wider and has better transmission characteristics. However, the 3-5 micrometer band is more efficient for finding operating targets (Antoniotti, 1986).

1.4 Missile Guidance

There are two main phases of guidance for an air-to-ground missile, midcourse and terminal. The purpose of the midcourse phase is to guide the missile into a certain acquisition basket so that terminal guidance can begin. The basket is an area defined by azimuth and elevation where the missile must pass through when beginning terminal guidance if target acquisition is to occur. If a missile has an acquisition basket with limits of +/- 20 degrees azimuth and +/-6 degrees elevation, the potential target must be within 20 degrees azimuth and 6 degrees of elevation of the missile's line of sight as it passes through the basket (Dargan, 1993).

During the midcourse guidance phase, navigation is controlled by the Inertial Navigation System (INS). The midcourse guidance phase of a Hellfire missile begins shortly after launch. In inertial guidance, the fire control system provides the aircraft and target velocity and position data to the missile at launch. During flight, the missile uses the initial position data and inertial navigation to remain on course (Eichblatt, 1989).

Inertial navigation is the process of providing position and velocity of the missile with respect to a reference point based solely on inputs from self-contained acceleration sensing instruments. Gyroscopes provide the acceleration data, while accelerometers provide the magnitude of the acceleration. The sensed acceleration vector data, corrected for gravity, is integrated to obtain vehicle velocity. The velocity data is then integrated to obtain vehicle position. At a predetermined point, the seeker is activated and the terminal guidance phase begins.

A seeker is a system that processes information from a sensor for use by the missile guidance system. Seekers are classified as either passive or active. A passive system detects energy emitted by or reflected off the target. The energy emitted from the target can be a byproduct produced during operation or energy from a natural source such as the sun. An active system produces energy that is transmitted to the target where it is reflected back in the direction of the seeker. For an active system, the information extracted from the energy returns are range, azimuth angle, and elevation angle of the target along the seeker line-of-sight. A passive system does not directly provide range information, only angle information. Whether the seeker is active or passive, the basic concept involves the seeker receiving reflected energy; laser, IR or Radio Frequency (RF), from the target. The energy from the target is used by the guidance system to survey, acquire and to lock-on and track the target. (Dargan, 1993)

During the terminal guidance phase, the INS updates are suspended and the seeker provides targeting information to the guidance processor. The purpose of terminal guidance is to guide the missile to impact with the target. This includes scanning the suspected target location and identifying targets. Identifying targets requires the analysis

of signals from potential targets and discriminating between targets and non-targets. This implies that the seeker must be sensitive and have the capability to discern minute details about physical characteristics of possible targets. The seeker sends the information concerning possible targets to the missile guidance section. The guidance processor uses the signals from the seeker and the target detection and classification algorithm contained in the image processor to locate and track targets. Shortly before impact, the seeker updates are suspended and the missile continues without course changes until target impact (Dargan, 1993).

1.5 Army Aviation and Precision Guided weapons

Airborne, low-flying vehicles like today's attack helicopters possess the capability to deliver precise, lethal fires without massing forces. Attack helicopters are a unique maneuver asset to the ground force commander that contributes to all forms of offensive and defensive combat. Precision weapons are essential to the success of low-flying vehicles and increase their lethality. The precision weapon of the AH-64 Apache helicopter is the Hellfire missile. The Hellfire missiles currently in service consist of a semi-active laser (SAL) model and a radio frequency (RF) model. The RF missile is also known as a millimeter wave (MMW) missile since it employs active millimeter wave radar for guidance. The SAL missile uses reflected laser energy to home on targets. A target must be painted with a coded laser that matches the Pulse Repetition Frequency (PRF) code programmed into the missile. While in flight, the missile acquires the laser energy reflected off the target and navigates to the reflecting point. Hellfire missiles with a semi-active laser seeker guidance system use reflected laser energy with a wavelength

of approximately 1.06 micrometers. The SAL missile is used with the standard AH-64 Apache and the RF missile is used with AH-64D Longbow Apache ("USA: Air to Surface Missiles", *Jane's Air Launched Weapons*, 1997). These missiles are adequate for the missions, platforms and threat at present. However, the future force structure of the Army mandates the development of improved weapon systems with greater range and improved accuracy. Army aviation will become a leaner force due to funding challenges but mission requirements will not decrease. The only viable method to meet the demands is through increased lethality of weapons and increased flexibility of platforms (Army Aviation Modernization Plan, 1998 update).

A review of the Army aviation modernization plan indicates that Hellfire III is a planned future weapon system that will help Army aviation increase the capabilities of attack helicopters and meet mission requirements. The Hellfire III missile is an improved Hellfire missile that will be compatible with current and future Hellfire launchers. Possible benefits of the Hellfire III include cost reduction, weight reduction, increased range, increased utility and improved accuracy. New weapons and aircraft are only a portion of the modernization effort. The planned procurement of other systems which support information dominance are also crucial to the modernization of aviation and the ability of aviation units to conduct operations in the future. Therefore, it is essential that new systems under development maximize utility and performance while minimizing costs (1998 Army Aviation Modernization Plan).

Three seeker variants are being considered for the Hellfire III missile. Since the Army Aviation modernization Plan states that the Hellfire III must be compatible with present launchers, the Hellfire III will employ a dual seeker head concept with one of the

seekers supporting the SAL guidance systems. The second seeker head will be a Millimeter Wave (MMW), Imaging Infrared (IIR) or Laser detection and ranging (Ladar) guidance system. The dual seeker head concept increases the lethality of the Hellfire missile by permitting operation in a greater variety of environmental conditions. When one system is ineffective due to attenuation of the electromagnetic spectrum, the other system will ensure accurate terminal guidance. An additional benefit is achieved through the autonomous nature of the missile. Self-guidance translates into reducing exposure of the shooter to enemy fire. Additionally, self-guidance increases stand-off ranges by eliminating the requirement of a designator maintaining line-of-sight on the target until missile impact.

The millimeter wave missile has an active radar that enables self-navigational capabilities. Prior to launch, the MMW missile is given approximate target location data by the Longbow fire control radar or via digital datalink. The missile can be fired in Lock on before launch (LOBL) or Lock On After Launch (LOAL) mode. After launch, the MMW Hellfire flies toward the approximate target location while searching for the target. The MMW missile compares the radar return from possible targets to known target descriptions. The millimeter wave system's performance is sufficient to be able to distinguish individual tanks, highly accurate and capable of operation in adverse weather. The following MMW Characteristics are described by Sundaram, in *Millimeter Waves - The much awaited Technological Breakthrough* :

1. Small size: The use of relatively short wavelength millimeter waves makes it possible to reduce the size of components. This translate into less weight and more room in a missile for the propulsion system or warhead.

2. High bandwidth: The four main windows 35, 94, 140 and 220 Ghz have available bandwidths on the order of 16, 23, 26 and 70 Ghz. Bandwidth is an advantage since at each millimeter wave window, extremely large bandwidths are available. The advantages this presents are considerable. There are many more frequencies that can be used. Thus there is an increased immunity to interference from friendly users (electromagnetic compatibility or EMC). It also makes jamming more difficult, unless the exact frequency to be jammed is known. The large bandwidths also make radars more sensitive to Doppler frequency shift measurements. The Doppler frequency shifts are used for target discrimination.

3. Low beamwidth: For a given antenna size, smaller radiated beamwidths are possible, providing higher resolution and hence better precision. This is very important in target tracking where the smaller beamwidths can pick out more details and can discriminate better against small targets.

4. Atmospheric losses: Atmospheric absorption and attenuation losses are relatively low in the transmission windows, compared to the problems faced by laser or IR transmissions in rain, fog and smoke. Millimeter wave sensors are therefore more effective than Electro-Optical (EO) sensors in adverse weather or battlefield smoke/dust conditions.

An imaging guidance system differs from non-imaging by reproducing the scene within its field of view (Eichblatt, 1989). Imaging infrared (IIR) seekers are electro-optical systems that work by discerning temperature signatures of targets from that of the background. They produce a picture that is a map of temperature differences across an extended target (Dereniak, 1996). To accomplish this, IIR seekers rely on a technology known as focal plane Array (FPA) to detect the inherent heat of the target, whether self-generated or absorbed earlier from external sources such as solar radiation, to produce a high level of resolution. Focal plane arrays use thousands of microcircuit detector elements per array and provide nearly 24-hour imaging sensor capability comparable to visible light electro-optics or TV scanners (Daskal, 1990). However, IIR seekers are incapable of detecting targets at thermal crossover if they are not producing heat. Thermal crossover occurs twice daily and is the time period when the ambient

temperature is equal to the temperature of targets. If the background temperature and target temperature is the same, the missile cannot generate an image of the target (Holst, 1995). IIR seekers have some resistance to atmospheric absorption that would limit normal IR systems. IIR sensors, especially those operating in the infrared regions of 8.0 - 11.0 micrometers and 9.0 - 13.5 micrometers, have some ability to penetrate fog, smoke and light precipitation (Daskal, 1990).

A new revolution in surveillance technology that is showing promise for precision guided weapons is imaging laser radar (Ladar). Ladar is an active electro-optical system that operates at wavelengths ranging from below 1 mm to over 10 mm. Ladar works in the same manner as a radar seeker such as the MMW seeker. The ladar seeker is an active seeker that sends out pulses of energy and forms an image frame from the energy returns. Ladar proponents insist it is cheaper, less complex, and more reliable than radar, and because of its quick-scanning narrow beam width, ladar proposes less risk of revealing its presence to the enemy (Keller, 1993). The three primary advantages of ladar over competing sensors such as millimeter wave and imaging infrared are high resolution, signature stability and the ability to produce a three-dimensional image. High resolution, three-dimensional imaging and signature stability facilitate target recognition. High resolution and signature stability are essential to the development of a good image and the three-dimensional capability enhances the image. This results in an increased target recognition capability when the rendered image is compared to imaging data stored in the target identification system (Stargardt, 1997). The Ladar seeker can operate in adverse, but not all weather. Haze, fog and clouds affect Ladar more severely than millimeter wave radar (Dargan, 1993).

In general, it can be said that shorter wavelengths result in higher resolution and therefore better target discrimination but longer wavelengths result in operations in more environmental conditions. Millimeter wave systems do not have the extremely high resolution of their electro-optical counterparts but have superior penetrability through the smoke, fog and rain. Higher frequencies provide greater resolution and discrimination but are also subject to greater attenuation. This is because that at higher frequencies, the wavelengths are similar in size to the rain and fog particles. Therefore, the energy is absorbed. Millimeter waves thus represent a compromise region where most of the advantageous characteristics of the microwave and electro-optical (EO) regions are available while the disadvantageous effects are minimized (Sundaram, 1979).

1.6 Evaluation of Advanced Precision Guided Weapons

Advanced air-to-ground missiles use four systems during flight; navigation, seeker, guidance and control. During the midcourse phase, the navigation system determines the position, velocity and acceleration of the missile with respect to a reference frame such as the earth and sends signals to the guidance system. During the terminal phase, the seeker system processes information from a sensor and sends signals to the guidance system. The guidance system uses the signals from the navigation system or seeker system to determine the corrections necessary to keep the missile on course and sends signals to the control system. The control system changes the flight path of the missile based on the inputs from the guidance section (Dargan, 1993).

The performance evaluation of a theoretical advanced air-to-ground missile is a complex task and depends on several factors. A valid answer cannot be achieved without

considering the planned employment techniques of the advanced precision guided missile, the future of the delivery platforms, and the Army Modernization Plan. It is only after these factors are considered and completely defined that performance objectives of the proposed advanced air-to-ground missile can be stated. The performance objectives must be tempered with the performance capabilities of the navigation system and seeker system. The performance objectives provide the basis for the evaluation of the missile. The question then becomes, what tools and methodology should be used to evaluate the different navigation and seeker technologies currently available to ensure the performance objectives are fully investigated and that a credible solution is obtained?

CHAPTER 2

SIMULATION AND ACQUISITION

2.1 Simulation and Weapon Systems

"Modeling and simulation (M&S) tools are rapidly evolving as the method of choice for addressing problems in developing systems and providing early insight into life cycle issues regarding the systems. Whether the problem arises in engineering and manufacturing development (EMD), combat development, test and evaluation (T&E), training, or operations and support concepts, chances are that a model or simulation exists that the project managers (PMs) can use to assist in the solving of the problem. At a minimum, M&S can help clarify the variables affecting the problem and identify potential trade-offs that can impact the decision." (Kotchman and Glasgow, 1998)

The integration of modeling and simulation (M&S) into the development plan of a new system can offset declining funding resources, decrease developmental timelines and reduce the risks associated with a new system. M&S should be a thoroughly considered and integrated component of the development plan. Virtual, live and constructive simulations should be used throughout the development of a system to support the individual phases and help to provide feedback and product insight. Through the use of M&S, operational issues can be explored, costs can be predicted and the results or proposed design changes can be analyzed. An area of importance that can be investigated through the use of M&S is the operational effectiveness of a proposed system. Through the use of virtual simulations, the capabilities of a proposed system can be evaluated to determine if the performance characteristics are cost efficient. Additionally, doctrinal

employment concepts can be tested to determine the most effective means for utilization. Thoroughly evaluating a proposed weapon system in a virtual environment that accurately represents real world conditions enables the development team to identify performance deficiencies and make design corrections that facilitate desirable performance while reducing the risk of developing a system that is inadequate. An expensive new system that offers little improvement over currently available systems is a waste of resources (Kotchman and Glasgow, 1998).

A critical consideration of virtual simulations when evaluating weapons systems is scenario credibility. The scenarios developed to test the new system should be designed by people who understand military scenarios and be based on doctrinal concepts and realistic threat actions. The capabilities of the threat force, friendly force and weapon system under evaluation must be accurately replicated to avoid entering bias into the output data. A primitive Computer Generated Force (CGF) system or weapon system implementation without accurate characteristics will yield untrustworthy results. Additionally, the general concept of the simulation must be developed so that the output data required to thoroughly evaluate the system and make a decision is obtained. Also, care must be taken to ensure the results are independent of the general concept of the simulation (Craft and Carr, 1997).

2.2 Constructive Simulation of Missiles and Its Effectiveness

One method of testing and evaluating precision guided munitions is through the use of constructive simulations. Constructive simulation models consist of mathematical models constructed in order to represent real world phenomena. They involve simulated

people operating simulated systems. People, equipment, and interactions are simulated in a synthetic world. Real people stimulate (make inputs to) such simulations, but are not involved in determining the outcomes (DoD 5000.59-P). These models represent the precision guided missiles in a simulated battle and use algorithms to project the missile's characteristics and capabilities into the simulation. The models seek to evaluate the effectiveness of the missiles and their contribution to the success of the friendly force through measuring the missile's capability to destroy enemy targets. Understanding how current models do this will indicate to what extent they measure the characteristics of a precision guided weapon required to make valid design decisions.

ModSAF, which is an acronym for Modular Semi-Automated Forces, can be used to evaluate missile effectiveness. ModSAF is a Distributed Interactive Simulation (DIS) system that portrays Computer Generated Forces (CGF) with realistic individual and unit behaviors. The system is sponsored by the Defense Advanced Research Projects Agency (DARPA) WISSARD (What If Simulation System for Advance Research and Development) project. ModSAF simulated entities can behave autonomously; they can move, shoot, communicate, and react without operator intervention. The number of entities is maximized by simulating only those features that are externally observable or significant to other simulation exercise participants, and by automating the low-level decision making of the entities. The goal of ModSAF is to replicate the outward behavior of simulated units and their component vehicle and weapon systems to a level of realism sufficient for training and combat development. A ModSAF entity is given extensive capabilities; it can drive over terrain avoiding obstacles, shoot at enemy objects, and be tasked to execute missions. Capabilities are based on, but are not limited to, such

appropriate factors as range, motion, activity, visibility, direction, orders and evaluation of threat. The ModSAF architecture is both flexible and hierarchical. It allows a researcher to embed other behavioral representations within the architecture, and it provides support for explanation, inspection, and modification of behavior (ModSAF Software Architecture design and Overview Document).

One area of weakness in ModSAF is the replication of precision guided missiles. As an example, consider the Hellfire missile. When the AH-64 Apache is serving as the launching platform, Hellfire engagements are not realistic. To date, at least two software concepts have been used to attempt to make simulated Hellfire missiles accurately replicate the real world entities. The first method involved trying to accurately replicate all aspects of a Hellfire engagement. This included considering the flight characteristics of the Hellfire missile and using the data for computing and showing a realistic fly-out. The Hellfire's physical and behavioral characteristics were modeled by loading simplistic algorithms that were derived from generic data into the main simulation. This was computationally expensive. Furthermore, inspection revealed that the important aspects of a Hellfire engagement are the launch, flight time and interaction with the target. An accurately replicated flight path is not required where player interaction with the model is not being considered. These facts, coupled with credibility issues surrounding the missile flight characteristic data mandated a change (Williams, 1999).

The second and current method uses a procedure that does not consider the flight path of missiles. Hellfire missiles are replicated in the same manner as tank main rounds and other ballistic weapons. The method uses information stored in the launching vehicle's parameter file and four libraries. The libraries are libvspotter, libvassess, libroe

and libbalgun. The libraries are a collection of computer code which comprise the routines and implementation data that allow ModSAF to perform the functions necessary to replicate realistic behaviors. The general concept is that a possible target is detected, processed to determine if it meets the criteria to be attacked and then attacked through the use of a ballistic gun or disregarded. Attacking with a ballistic gun implies that at launch time an instantaneous determination is made if the missile hits the target. The missile is graphically represented but it is unaffected during flight by environmental factors or obstacles. Additionally the target entity cannot explicitly employ countermeasures against the missile, with the exception of the SAL Hellfire, since the determination of a hit or miss is made at weapon launch. The SAL Hellfire behavior has a provision to nullify a hit. At the time of impact, the SAL Hellfire checks to ensure that the laser designator is still on the target. If the laser spot is off the target, a hit is changed to a miss. With self-guiding missiles, this behavior does not exist. Countermeasures such as the Active Protection System (APS) can be portrayed implicitly with self-guiding missiles by adjusting the missile's Probability of hit (P-hit) or other abstract methods. However, the validity of these methods is controversial (Williams, 1999).

The parameters file of the launching vehicle contains the Hellfire specific information required for engagements. The information includes, but is not limited to, available missile types, required sensors, minimum missile range, maximum missile range, and range specific, weapon selection criteria. Hellfire engagements, depicted in Figure 2, begin with the acquisition of a possible target by a sensor.

The sensors feed the information to the libvspotter. Libvspotter implements a task that accumulates detected vehicles from the Apache's sensors. The AH-64D model

has a Longbow radar sensor, IR sensor and visual sensor. The AH-64A Apache has an IR sensor and visual sensor. The radar model calculates the radar cross section of a target based on the target type, range to target, and target aspect angle. If the radar cross section of a target is greater than a threshold based on the longbow radar's capabilities, the radar detects the target. The visual model detects targets based on the effective size of the target (actual size, aspect angle, range, and percent of target visible), eyepoint of the viewer, probability of detection and focus of attention. The IR model is similar to the visual model but includes calculations for IR signature strength in addition to effective target size. Following a detection, the target information is passed to libvassess. Libvassess implements a vehicle level task that identifies the most urgent target and makes recommendations for weapons to use against that target. The task takes the primary input from the libvspotter task that provides lists of Identified Friend or Foe (IFF) identified vehicles detected by available sensors. The priority list within libvassess is handled by libroe. When libvassess has completed the necessary functions, the target information is passed to libvtargetter.

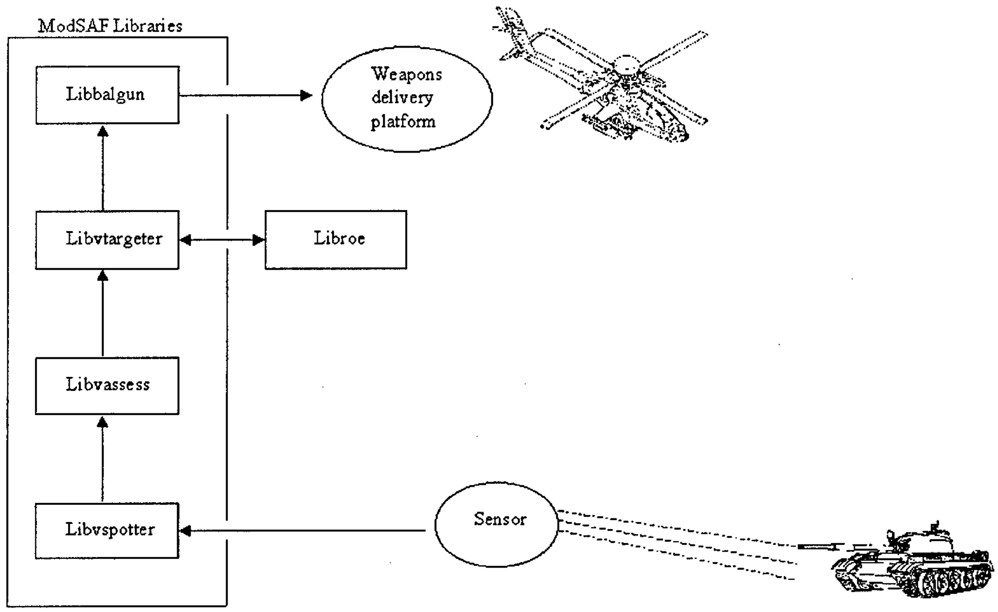

Figure 3. ModSAF Targeting Process

Libvtargeter implements a vehicle level task that collects threat information from libvassess and performs targeting actions against that threat by implementing an instance of the gun class of components. Libvtargeter controls libbalgun, as well as other libraries and directs the launch of the missile. It provides a low-fidelity model of generic ballistic gun behavior. Libbalgun enables the defining of rates of fire, min range, max range, engagement techniques, number of missiles in flight, the sensor in use and the probability of hit table to be used with the weapon. After launch, the missile is visually displayed but flies directly toward the target without regard to a realistic flight profile. Entity states are not produced for the missile, therefore it cannot be interacted with during flight. A hit model determines if the missile strikes the target. The hit model is influenced by the firer's velocity, and range to target, the target's vehicle type, aspect angle, velocity and

percent exposure (visibility). A probability of hit table is a component of the hit model. The hit table was derived directly from Army Material Systems Analysis Activity (AMSAA) data with a perfect laser spot accuracy using LDWSS. The table entries are:

1. Attack angle: An azimuth angle between the target heading and shooter heading using a 0-90 degree scale.
2. Range: Distance between the target and shooter.
3. Horizontal center of impact: Mean discrepancy between the desire horizontal aimpoint and the actual hit point.
4. Vertical center of impact: Mean discrepancy between the desire vertical aimpoint and the actual hit point.
5. Horizontal dispersion: Real measured values expressed in millimeters.
6. Vertical dispersion: Real measured values expressed in millimeters.

If the hit model concludes that a hit occurred, the target determines the extent of damage based on a damage model. Damage models define how particular weapons affect a particular entity. The angle of incidence of the impact, location of the hit, and the number of missiles that hit influence the severity of damage. A damage table is a component of the damage model. Damage tables are constructed from data maintained by AMSAA (Functional Description Document for ModSAF V3.0).

2.3 ModSAF with an Ordnance Server

An approach to simulating precision guided weapons in ModSAF that could be adapted for evaluation of Hellfire missiles is through the use of an Ordnance Server. The Ordnance Server (OS) is an external host that models weapons surrogates. The Ordnance Server extends the idea of distributed simulation by separating the simulation of the launching vehicle from the munition simulation. Validated weapon models are incorporated into the Ordnance Server and the corresponding ModSAF models are

disabled. This approach improves scalability, provides a more level playing field between interacting entities, and segregates sensitive or classified modeling and data. The Ordnance Server operates using standard DIS protocol data units (PDUs). When a cooperating launch vehicle fires a munition, a fire PDU is issued. The Ordnance Server sees the PDU and tries to match it to a weapon type it is configured to simulate. If a match is found, the Ordnance Server instantiates a simulation of that weapon using target data from the fire PDU. The Ordnance Server issues entity state PDUs for the instantiated munition during its delivery to target. When the fuze model indicates the termination of the munition, the Ordnance Server generates a detonation PDU (Ullom and Fischer, 1996).

Larry Ullom and Peter Fischer used an Ordnance Server with ModSAF to explore the viability of the configuration. The setup for the study involved several simple internal modifications to ModSAF. The internal weapon dynamics for the missile to be simulated by the OS was disabled; the ID number removed and the missile's entity state and detonation PDUs were suppressed. Additionally, a "Generate Missile" command was added to the ModSAF executable and the fire PDU was modified to include the designated target ID. The OS had two external interfaces; the Model Interface Adapter (MIA) and a ground truth database interpreter. The MIA was a code wrapper that went around the external weapon model and provided all the translation services needed to make the model look like an internal simulation while simulating the environment the external model was designed to operate in. The ground truth interpreter provided the OS with a consistent representation of ground truth regardless of the actual format used in the underlying terrain database (Ullom and Fischer, 1996).

The results of the study indicated that the ordnance server could be used to provide models that are accepted by subject matter experts with no penalty to the ModSAF application's processor load. Also, it is possible to maintain multiple models of a particular munition at different levels of detail using the OS approach. Ullom and Fischer also concluded that simulations that use the OS do not create munition simulations with unrealistic flight or guidance attributes. An added benefit of the realistic flight trajectory is that the missile's entity state PDUs generated during the missile's flight permit the target entity to track the missile as it approaches and take actions to avoid being hit. One additional benefit is the ease of implementation. Models integrated using the OS in the manner used by Ullom and Fischer do not have to be reengineered to fit within the ModSAF architecture, and multiple models of the same munition can be substituted easily (Ullom and Fischer, 1996).

2.4 ModSAF and Advanced Air-to-ground Missiles

Clearly, if ModSAF is to be used to evaluate the desirable attributes of advanced air-to-ground missiles, modifications must be made. Some problems are unrealistic effective ranges, susceptibility to network load, inaccuracy of seeker model, immunity to spoofing tactics, simplistic hit tables and simplistic kill tables (Ullom and Fischer, 1996). Before the modifications to ModSAF can be made, it is paramount to identify the desirable attributes that will be evaluated. Dr. Ephraim Martin, a senior defense analyst, has conducted research in this area. His thorough review of the Army's modernization plan and future force employment strategy has resulted in the defining of advanced air-to-ground missile general performance requirements that will support the plans. To

compliment his individual work, he developed a survey that was administered to Army Aviation Officers and other tactical decision-makers. Participants were required to compare and contrast seven missile performance attributes and provide numerical assessments of importance of each versus the others. The seven attributes were: lock on before launch /Fire & Forget capability, lock on after launch /Non Line Of Sight capability, all weather capability, ability to hit a moving target, ability to hit a stationary target, ability to kill a precision target, and countermeasures resistance. The results of the survey indicate that the most important performance attribute is the ability to hit a moving target. Additionally, the six other attributes were viewed to possess approximately the same importance. This indicates that the user community wants a very capable missile and that further research is required to identify specific performance attributes.

The results from the initial survey can be used to develop initial concepts of how to model an advanced air-to-ground missile in ModSAF. Analysis of the implications of the user communities responses indicates that the missile must be able to eliminate a moving target at a range up to 15 kilometers. This implies that the target must be detected, assessed and a decision made to engage the target. After launch, the advanced missile must have the capability to navigate to the target vicinity, detect the target and then perform terminal guidance with a high degree of accuracy. Also, the target must have the capability to employ a countermeasure or evasive procedure if it is a normal behavioral characteristic of the target. Research is required to define specific attributes that result in discernable output differences between the various seeker technologies when assessed through the use of a constructive simulation.

Modeling the advanced air-to-ground missile attributes requires a significant departure from the current methodology. Two research questions stem from this investigation: (1) Can a constructive model be built and incorporated in ModSAF that accurately represents critical identified attributes of advanced air-to-ground missiles and (2) What does multiple variant analysis indicate about the suitability of potential missile/seeker alternatives. Some questions must be answered to enable the process.

1. What are the desirable attributes of an advanced air-to-ground tactical missile?
2. What are the characteristics of the currently available seeker technologies?
3. What modifications must be made to ModSAF to facilitate realistic advanced air-to-ground tactical missile behaviors?
4. How can the model and constructive simulation be validated to ensure reliability and credibility?

The answer to the questions will be in the form of behaviors and ModSAF implementation strategies. While answering the questions, focus on what is important must be maintained. That is, the accurate replication of advanced air-to-ground missiles. The behaviors of the missiles, launching platforms and targets must be accurate.

CHAPTER 3

DEFINING THE METHODOLOGY

3.1 Research Question and Process

The main question addressed by this research is, can a constructive model be built and incorporated into ModSAF that accurately represents advanced air-to-ground tactical missiles and seeker performance? What does multiple variant analysis indicate about the suitability of potential missile/seeker alternatives? To answer these questions, several supporting questions must be answered.

1. What attributes of an advanced air-to-ground tactical missile need to be represented in the model?
   a. What is the maximum desirable range?
   b. Is Lock On After Launch (LOAL) important?
   c. Is Lock On Before Launch (LOBL) important?
   d. What accuracy is required?
   e. What weather performance is required?
   f. What countermeasure resistance is required?
2. What are the characteristics of the currently available seeker technologies?
   a. What is the range performance of each seeker?
   b. How does weather effect each seeker?
   c. What is the discrimination capability of each seeker?
   d. What is the accuracy of each seeker?
   e. What is the acquisition basket size of each seeker?
   f. How do the seekers detect and analyze targets?
3. What modifications must be made to ModSAF to facilitate realistic advanced air-to-ground tactical missile behaviors?
   a. What procedures must be used to facilitate realistic Hellfire engagements?
   b. How can the p-hit be accurately replicated?
      1) How can the midcourse guidance phase be replicated so that the flight path and navigation errors are accurate?

2) How can the terminal guidance phase be replicated so that the flight path and navigation errors are accurate?
3) How can the target employ countermeasure and evasive behaviors to avoid being hit if these are part of the real life behaviors?

c. How can a sensor be employed to facilitate the detection of the target while the launching platform remains out of line of sight?
d. How will the sensor and launching platform communicate to ensure the target information is properly processed?
e. What are the tactically correct behaviors that the launching platform will employ and how can the tactically correct launching platform behaviors be implemented?
f. How should the scenarios be set up to generate the important output data?

4. How can the model and constructive simulation be validated to ensure reliability and credibility?
   a. What output data is important?
   b. What metrics will provide the greatest assessment?
   c. How will the data be analyzed?

The research required to answer the main question and supporting questions will be accomplished in a six-step process that builds on work previously conducted by Dr. Ephram Martin. The six steps of the methodology are Need identification, current Equipment evaluation, Technology research, building constructive MOdels, Scenario development, and output data Analysis (NETMOSA).

The NETMOSA methodology began with a thorough review of Army modernization plans to identify a need for a new or improved weapon system. When a need is defined, the user community is surveyed to determine desired tactical performance requirements. The user survey takes the concept of a new weapon system and incorporates tactical considerations. If a similar system is currently fielded, the user community can also identify current system deficiencies. The output from the user survey will be a clear definition of the performance requirements of the new or improved weapon system. The performance requirements provide the general information required to orient the research of the currently available technologies. The characteristics of the

technologies are assessed against the performance requirements. The goal of the technology research is to develop the detailed attributes of the advanced air-to-ground missile and seeker that will be incorporated in the constructive simulation model. The attributes will be built into the constructive simulation as behaviors of the weapon system. After the models are built, the simulation scenarios are developed and run. The final step is the analysis of the data that is collected during the running of the simulations. Concurrent with these steps, a feedback loop helps to correct problems as they become evident.

This research is based on the results of a review of the Army Aviation Modernization Plan that identified the need for an improved air-to-ground missile (Hellfire III). Figure 4 is a graphical representation of the NETMOSA methodology that will be used for the advanced air-to-ground missile research. The output from the user survey will be tactical performance requirements of an advanced air-to-ground missile. The performance requirements will focus the research of the characteristics of the millimeter wave (MMW), imaging infra-red and ladar technologies. The performance characteristics of each seeker will be assessed against the performance requirements. The goal of the technology research is to develop the detailed attributes of the advanced air-to-ground missile and seeker that will be incorporated in the constructive simulation as behaviors of the seeker. Additionally, the performance characteristics of the missiles, independent of the seekers, must be quantified. Although the performance of the missiles will not vary from seeker to seeker, the performance characteristics must be addressed if a valid assessment of the air-to-ground missile is to be made.

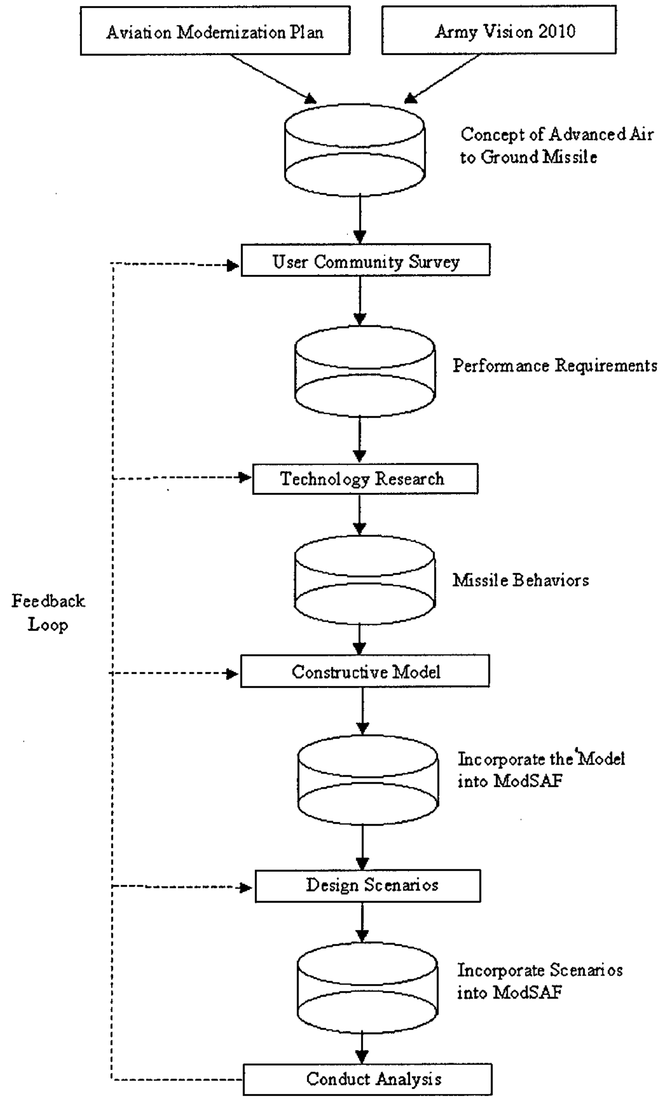

Figure 4. NETMOSA Research Methodology

3.2 Determining the Performance Requirements

The determination of performance requirements requires a through knowledge of the possible employment techniques of the advanced air-to-ground missile and the Army's future force structure. As mentioned earlier, Dr. Ephraim Martin has done some

work in this area. Refining his work requires using similar techniques. The first step is to filter the data that he has collected, identify central themes and develop a survey with a narrow focus to explore the central themes in greater detail. This requires significant input from the users.

The initial results indicated that users placed high value on being able to hit moving targets at ranges that exceed the current capabilities of the Hellfire missile. They also felt that it was important to have a very accurate, all weather, autonomous missile that is resistant to countermeasures. Since such a missile is cost prohibitive, a second survey is required to further explore performance requirements. The method of paired comparisons has been selected to evaluate the attributes of lock on before launch (LOBL), lock on after launch (LOAL), countermeasure resistance (CMR), all weather capability (ALL WX), capability to hit a stationary target (ST) and precision accuracy (PREC). The method of paired comparisons is described by John Canada and William Sullivan in their book, *Economic and Multiattribute Evaluation of Advanced Manufacturing Systems.* Using this method, a survey form must be created that requires participants to compare two attributes at a time and make preference judgments. The responses of each individual will be transcribed to a matrix and total preference values obtained. The blank matrix that will be used is depicted in Figure 5. The data will be transcribed by entering the matrix in the left vertical column at the proper attribute and then entering a value of 1 under each attribute that the entering attribute was preferred over. The final step involves the tallying of all preferences to determine the performance attributes considered most important by the survey participants. The performance attribute with the largest sum total is the most preferred attribute.

	LOAL	LOBL	ALL WX	CMR	ST	PREC	Total
LOAL							
LOBL							
ALL WX							
CMR							
ST							
PREC							

Figure 5. Matrix used for Pair Wise Comparison of Performance Attributes

3.3 Researching the Available Technologies

The current technologies must be understood and compared to obtain a clear picture of the inherent strengths and weaknesses of each. The strengths and weaknesses translate into behaviors that will be incorporated into ModSAF. This must be accomplished in sufficient detail to facilitate accurate replication of each technology in the constructive simulation. The areas to be explored are performance in varying environmental conditions, target discrimination ability, acquisition basket requirements and terminal guidance capabilities. A complete understanding of the technologies is essential to eliminating potential bias and producing credible results.

The research into the effects of environmental conditions focuses on the seekers capability to function in moderate and adverse weather. Moderate weather is defined as atmospheric conditions that produce normal attenuation of the electromagnetic spectrum.

The performance of the seekers is not degraded by moderate weather. Adverse weather is defined as atmospheric conditions with a rain rate of 4mm per hour. This provides the capability to discriminate between the seeker technologies based on weather. The rain rate of 4mm per hour was chosen based on independent research conducted by V.W.Richard and Clifton Stargardt and the fact that it is a rate which can reasonably be expected to occur in nature. Richard discovered discernable attenuation differences between millimeter wave, infra-red and ladar when rain fell at a rate of 4mm per hour. Additionally, Stargardt noted performance limitations of ladar at rain rates of 4mm per hour and above. The MMW seeker is resistant to adverse weather conditions and shows minimal degradation while the performance of IIR and Ladar seekers are severely degraded during adverse weather.

Analysis of the acquisition basket is accomplished through the conversion of the characteristics into common terms. This process has the added advantage of protecting proprietary and sensitive information since it is a form of encoding the information. The process of converting the characteristics into common terms was accomplished by establishing a baseline using the characteristics of the MMW seeker, against a moving target in moderate weather. This was an arbitrary assignment and involved the simple process of assigning a value of 1.0 (Equation 1) to all characteristics of the MMW seeker against a moving target in moderate weather.

$$1.0 = \frac{\text{Max Terminal Guide Range, MMW, Mod Weather, Moving Target}}{\text{Max Terminal Guide Range, MMW, Mod Weather, Moving Target}} \tag{1}$$

The other seekers were then compared against the baseline in both moderate and adverse weather, as well as against stationary and moving targets. The comparison was accomplished through simple division (Equation 2) where the target characteristic data of the other seekers were divided by the same data (maximum range, azimuth, elevation) belonging to the MMW seeker against a moving target in moderate weather.

$$\text{TableInput} = \frac{\text{MaxTermGuideRange,Ladar,ModWeather,StationaryTarget}}{\text{MaxTermGuideRange,MMW,ModWeather,MovingTarget}} \qquad (2)$$

The results of the comparisons are listed in Table 1 and reveal that while the IIR and Ladar seekers have the same azimuth (horizontal) and elevation (vertical) capabilities for both moving and stationary targets, weather performance capability as expressed by maximum range is significant. It is also apparent that the MMW seeker is only affected by the target's disposition concerning movement. If the target is stationary, the acquisition basket is 1/5 as large with regards to azimuth but twice as large with regards to elevation than if the target is moving. This is due to the MMW's reliance on Doppler frequency shifts to identify targets but does not provide enough information for detailed analysis of results. If the elevation characteristics are relatively small and the azimuth characteristics are very large, the significance of the reliance on the Doppler shift will be minimized. To fully appreciate the impact of the effects of weather and target disposition on the seekers, the length and width of the field of regard must be examined.

Table 1

Acquisition Baskets of the Seekers (Normalized with MMW moving, moderate weather data designated as baseline information)

Seeker/Target Action	Weather	Max Range	Azimuth	Elevation
Ladar: moving	Moderate	.43	+/-1.0	+/-1.5
Ladar: moving	Adverse	.17	+/-1.0	+/-1.5
Ladar: stationary	Moderate	.43	+/-0.3	+/-4.0
Ladar: stationary	Adverse	.17	+/-0.3	+/-4.0
IIR: moving	Moderate	.61	+/-1.0	+/-1.5
IIR: moving	Adverse	.33	+/-1.0	+/-1.5
IIR: stationary	Moderate	.61	+/-0.3	+/-4.0
IIR: stationary	Adverse	.33	+/-0.3	+/-4.0
MMW: moving	Moderate	1.0	+/-1.0	+/-1.0
MMW: moving	Adverse	1.0	+/-1.0	+/-1.0
MMW: stationary	Moderate	1.0	+/-0.2	+/-2.0
MMW: stationary	Adverse	1.0	+/-0.2	+/-2.0

Knowing the size of the acquisition basket enables us to calculate the size of the field of regard of each seeker. The field of regard is the area searched by the seeker as it attempts to locate a target. The length of the field of regard can be calculated through the use of basic trigonometry. The required items of information are the maximum range of the seeker, the missile's height above ground when the seeker begins the search and the

vertical traversing capabilities of the seeker. The basic elements required to determine the size of a field of regard are shown in Figure 6.

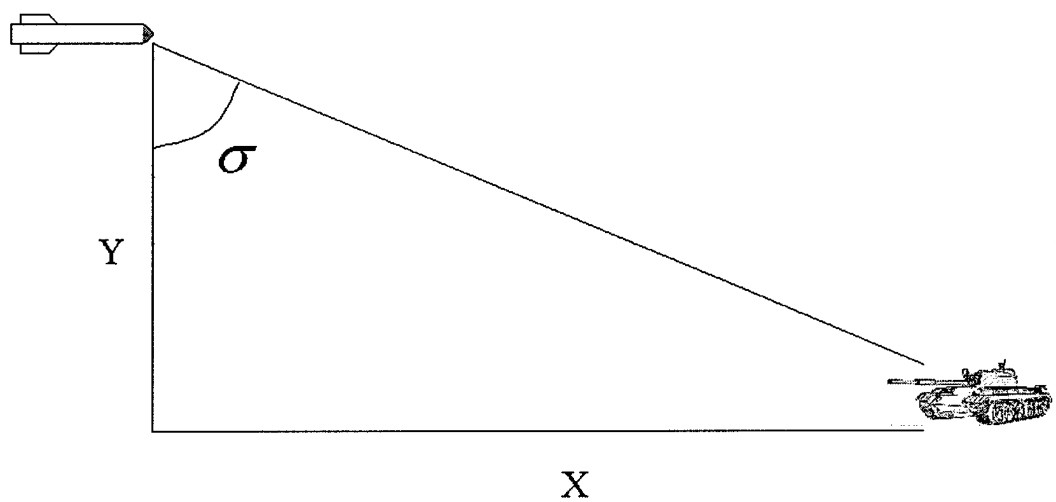

Figure 6. Determining the Length of the Field of Regard

The seeker can traverse z degrees up from the center position and z degrees down from the center position. Therefore, the total traversing range is 2z degrees. To compute the maximum length of the field of regard, the seeker is assumed to be at the top of its vertical transverse when scanning at the maximum range. This permits the determination of the length from the maximum range to -2z. The point at the maximum range is called the toe and the point at -2z is known as the heel. The angle from the missile to the toe is computed using Equation 3.

$$\sigma = Tan^{-1}\frac{X}{Y} \tag{3}$$

The angle to the heel is σ - 2z. The distance from the missile is then computed using Equation 4.

$$Tan\,(\sigma - 2z) = x \tag{4}$$

The total length of the field of regard is the distance between the toe and the heel. The width of the field of regard is determined using the mil relation formula. Since 1 degree equals 17.78 mils, we multiply 17.78 by the number of degrees associated with the seeker's horizontal traverse capabilities and then multiply that sum by the range to the toe divided by 1000. This results in the width of the field of regard at the toe expressed in meters. The same process is used to determine the width of the field of regard at the heel. Once the length and width of the field of regard was computed a baseline was established using the characteristics of the MMW seeker, against a moving target in moderate weather. The characteristics for the other seekers were then divided by the characteristics of the MMW seeker against a moving target in moderate weather and a percentage was obtained. The fields of regards at specific ranges are listed in Table 2.

Table 2

Seeker Fields of Regard at Maximum Terminal Guidance Range (Normalized with MMW moving, moderate weather data designated as baseline information)

Weather	MMW moving	MMW stationary	IIR moving	IIR stationary	Ladar moving	Ladar stationary
Moderate	1.0 x1.0	.2 x 2	.61 x .92	.18 x 2.90	.43 x .64	.13 x 1.71
Adverse	1.0 x1.0	.2 x 2	.33 x .49	.10 x 1.31	.17 x. 26	.05 x .69

Analysis of Table 2 shows that the IIR and Ladar seekers have larger fields of regard in moderate weather than they do in adverse weather. This is due to the fact that the IIR and Ladar seekers have a longer terminal guidance range in moderate weather than they do in adverse weather. It is also apparent that a difference exists between the azimuth and elevation characteristics in varying conditions. This implies that different employment techniques have the possibility of producing different outcomes. For example, if the advanced air-to-ground missiles engage a moving enemy force from the flank, the results may be different than if they engaged the same moving enemy force from the front.

Another way to analyze the seekers is through the comparison of the total area of the field of regard. The total area of the field of regard was determined using the dimensions computed through the use of Equation 3, Equation 4 and the mil relation formula. Once the dimensions were known, the formula to determine the area of a trapezoid was employed to determine the total area of each field of regard. The total area

was then normalized using the same procedure utilized for the development of Tables 1 and 2. The total area of each Field of Regard is listed in Table 3.

Table 3

Field of Regard Total Area (Normalized with MMW moving, moderate weather data designated as baseline information)

Seeker/Target action	Weather	Area
Ladar: moving	Moderate	0.17
Ladar: moving	Adverse	0.02
Ladar: stationary	Moderate	0.06
Ladar: stationary	Adverse	0.01
IIR: moving	Moderate	0.37
IIR: moving	Adverse	0.09
IIR: stationary	Moderate	0.13
IIR: stationary	Adverse	0.03
MMW: moving	Moderate	1.00
MMW: moving	Adverse	1.00
MMW: stationary	Moderate	0.22
MMW: stationary	Adverse	0.22

Evaluating the total areas of the fields of regard, it is apparent that the MMW seeker against a moving target has the greatest area of coverage. Therefore, we can expect the MMW seeker to perform the best against moving targets. Against stationary

targets, the IIR seeker has the largest area of coverage in moderate weather and the MMW wave seeker has the largest area of coverage in adverse weather.

The affects of missile drift were evaluated after the dimensions and physical characteristics of the various fields of regard were known. Determining the affect that drift will have on the outcome of Hellfire engagements involves the comparison of the half-widths of various fields of regard to the lateral displacement caused by drift. Both the field of regard width and the lateral drift displacement are seeker and weather dependent. Since the width of a field of regard increases as the distance from the missile increases, a standard point within the field of regard must be chosen for comparison purposes. This point, referred to as the arch, was selected to be the σ -1z point for all seekers in both weather conditions. The width was then determined by computing the range to the arch for a specific seeker/weather combination and then determining the width based on the horizontal traversing capabilities of the seeker for the same seeker/weather combination. This is the same procedure that was used when analyzing the size of the various fields of regard. The half-width is simply the width at the arch divided by 2. The half-width at the arch is used since the target will ideally be located in the horizontal center of the field of regard on the arch as depicted in Figure 7. The "ideal" location coincides with the center of both the vertical and horizontal traversing capabilities of the seekers. If an error greater than the half-width occurs, the intended target will not be located in the field of regard.

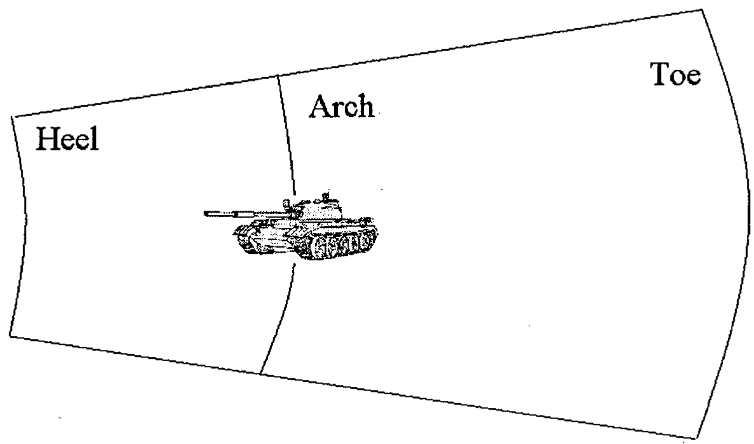

Figure 7. Ideal Plotting of the Field of Regard

The lateral drift displacement reasonably expected to occur during an average Hellfire III engagement was computed from an arbitrary launch point to the point at which terminal guidance would begin. This provided a total length that was less than the maximum capability of each seeker/missile combination. The length of the mid-course guidance range for each seeker/weather combination was computed and used to determine the time independent and time dependent drift components of total drift. The drift was based on an assumed 1-standard deviation error for both time dependent and time independent drift. Variability in the lateral drift between the various seeker/weather combinations exists because there is variability in the terminal guidance range of the seeker/weather combinations. Table 4 is a normalized comparison of the lateral drifts for

each seeker/weather combination. The lateral drift of the MMW seeker serves as a baseline and has the same rating for both moderate and adverse weather because the terminal guidance range is the same for both moderate and adverse weather. Since the MMW seeker has the longest terminal guidance range it has the shortest mid-course guidance range and therefore the smallest lateral drift. These results are based on the principle that the magnitude of lateral drift increases as the length of the mid-course guidance range increases.

Table 4

Normalized Comparison of the Lateral displacement Caused by Drift experienced by the various Seeker and weather combinations

	MMW	IIR	LADAR
Moderate	1.0	1.32	1.47
Adverse	1.0	1.56	1.71

The comparison of the lateral drift displacement of a specific seeker/weather combination and the field of regard for the same seeker/weather combination was accomplished by dividing the total drift by the half-width of the field of regard at the arch. The results are listed in Table 5. In the table, total drift is expressed as a percentage of the half-width of the field of regard at the arch. The table values for the adverse weather row, with the exception of the MMW columns, are higher than the values in the moderate weather row. This is due to the fact that the seekers, with the

exception of the MMW seekers have a shorter terminal guidance range in adverse weather.

Table 5

Comparison of Total Drift to the Half-Width of the Seeker field of Regard

	MMW moving	MMW Stationary	IIR Moving	IIR Stationary	Ladar Moving	Ladar Stationary
Moderate	.05	.37	.11	.61	.15	.78
Adverse	.05	.37	.19	.94	.34	1.5

The Table 5 values are total drift for a 1-standard deviation error. The 2-standard deviation and 3-standard deviation error values can be obtained by multiplying the values by 2 and 3 respectively. A value greater than 1.0 indicates that the error is greater than the width of the field of regard. If the error is greater than the width, terminal guidance will begin at a point that is significantly different from the point at which terminal guidance should have begun. This will result in the intended target being outside of the field of regard and the seeker will not acquire the intended target. Analysis of the Table 5 values indicates that if a drift equal to 1-standard deviation in both time dependent and time independent drift is realized, only the Ladar seeker against a stationary target in adverse weather will experience an intended target out of the field of regard. All other seeker/weather combinations will result in the intended target being in the seeker's field of regard. However, a 2-standard deviation error in both time dependent and time

independent drift will result in the intended target being outside of the field of regard for the IIR stationary/moderate, IIR stationary/adverse, Ladar stationary/moderate and Ladar stationary/adverse seeker/weather combinations.

The target detection capability of a seeker is directly related to the range performance of the seeker. The range performance of the seeker can be determined through the use of the ladar range equation for an electro-optical seeker, or through the radar range equation for a MMW seeker. The Ladar range equation is Equation 5

$$PR = \frac{PT \;\; \mathrm{G} \;\; \mathrm{AE} \;\; \sigma T_{OS}^{2} \; e^{-2\alpha R}}{(4\pi)^2 R^4} Watts \tag{5}$$

P_R = Power received
P_T = Laser Peak output power
G = Optics antenna gain
A_E = Effective aperture
σ = Laser radar cross section
T_{OS} =One way losses within laser radar
∝ = Atmospheric attenuation coefficient
R = range to target

The signal-to-noise ratio (SNR) is the ratio of the power received to the noise power contained in the receiver and the atmosphere. The SNR determines the probability of detecting a target. Equation 6, the signal to noise ratio for an electo-optical system, is:

$$\frac{S}{N} = \frac{P_T G A_E \quad T^2 os\, e^{-2 \quad R}}{(4\pi)^2 R^4 \left[\frac{2h\nu B}{\eta}\right]} \text{Watts} \tag{6}$$

H = Planck's Constant = 6.626×10^{-34} J
ν= Photon frequency
B = Noise bandwidth
η = Quantum efficiency

The radar range equation and signal-to-noise for a MMW seeker are:

$$P_R = \frac{P_T G^2 \sigma \lambda^2}{(4\pi)^2 R^4} \tag{7}$$

P_R = Power received
P_T = Power transmitted
G = Antenna gain
λ = Transmit wavelength
σ = Radar cross section
R = Range

$$\frac{S}{N} = \frac{P_T G^2 \sigma \lambda^2}{(4\pi)^3 R^4 k T_0 B} \tag{8}$$

k =Boltzmann's Constant = 1.38×10^{-23} J/deg
B = Receiver noise bandwidth
T_0 = Ideal receiver noise temperature = 290 deg K

The Hellfire III group at Lockheed Martin used Equations 5 through 8 during their analysis of the performance of the seekers in varying weather conditions. The output was a Probability of Acquisition (P-acq) of a target. Further analysis produced a Probability of Hit (P-hit) assuming an acquisition. Table 6 is a normalized comparison of the P-hit of each seeker assuming acquisition. The MMW seeker against a moving target in moderate weather serves as the baseline with a value of 1.0. The table values of the various seekers in varying weather conditions were generated by dividing the P-hit of the seekers in the various weather conditions by the P-hit of the MMW seeker in moderate weather against a moving target. It is interesting to note that the MMW and Ladar seekers have a table value of 1.0 for both the moderate and adverse weather conditions while the IIR seeker has a table value of 1.0 for moderate weather and a table value of .79 for adverse weather. This is a result of the target discrimination capability of the seekers. When identifying a target, the missile uses an image created from data obtained by the seeker's scan of an object and compares the scanned image to a target data base. If the scan matches a target image contained in the target data base, the object is determined to be a target. Of the three seekers, only the IIR is affected by adverse weather since the presence of moisture on a potential target changes the heat signature of the target and makes it unrecognizable. The MMW and Ladar seekers are immune to weather related signature modification since they are scanning the solid mass of a potential target.

Table 6

Seeker P-hit Data Based on Various Weather Conditions and Target Movement

	Weather Condition	
Seeker and Target State	Moderate Weather	Adverse Weather
MMW Moving	1.0	1.0
MMW stationary	1.0	1.0
IIR Moving	1.0	.79
IIR Stationary	1.0	.79
Ladar Moving	1.0	1.0
Ladar Stationary	1.0	1.0

The result of the research of performance in varying environmental conditions, target discrimination ability, acquisition basket requirements and terminal guidance capabilities was the development of a new method of determining if a hit or miss occurs when a Hellfire III missiles is fired in ModSAF. The new method is known as the Accumulated Missile Error and Target Action (AMETA) method and provides a significant improvement over the current procedure. The current procedure is simplistic and only involves a stochastic determination of a hit or miss based on a probability of hit number contained in the Libbalgun library. The outcome of a hit or miss is determined instantaneously when the missile is launched and is not influenced by weather or enemy actions. The AMETA algorithm is depicted in Figure 8 and described in subsequent paragraphs.

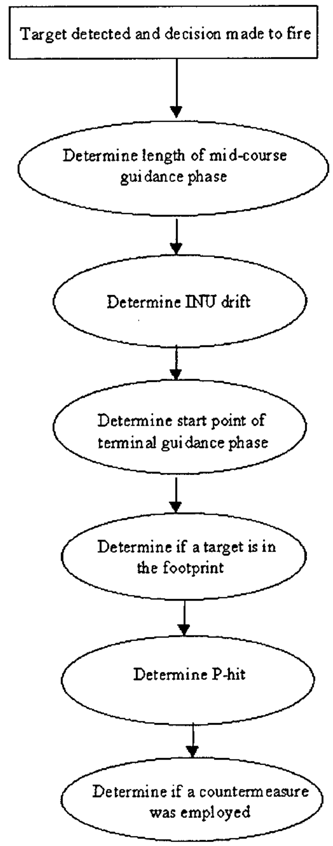

Figure 8. The Accumulated Missile Error and Target Action (AMETA) Algorithm

The Accumulated Missile Error and Target Action (AMETA) method uses the weather performance data to determine the maximum range at which the seeker can detect a target. The maximum range at which terminal guidance can begin is subtracted from the range to target to determine the length of the mid-course guidance phase. The missile will experience drift during flight due to the Inertial Navigation Unit (INU); therefore, drift must be considered. Total INU drift is the sum of the time independent

drift and the time dependent drift. The length of the mid-course guidance phase is used to determine a time of flight. The time of flight is used to compute time dependent drift. The time dependent drift error is then added to the time independent error to determine total drift. The INU drift errors accumulated in flight are used to determine the location of the missile when terminal guidance begins. The field of regard is then calculated and plotted when the missile reaches the terminal guidance start point to determine if the target is within the field of regard. This allows for the consideration of vehicle movement and target vehicle density. If the original target has moved outside of the field of regard, it will not be detected. However, other possible targets may have moved into the area where the field of regard is projected. The toe of the field of regard is plotted at the maximum range of the seeker. The angle from the seeker to the maximum range line when the search begins is known as σ. For this research, the computer code is written so that the seeker is at the top of its vertical traverse when scanning at the maximum range. The Arch of the seeker is located at σ -1z where z is defined as the seeker's vertical angular traverse from the neutral position to one of the vertical traverse stops. The heel of the field of regard is located at σ - 2z. Using this process, the maximum possible usable area is scanned for targets. The field of regard is plotted so that the aimpoint is centered horizontally in the field of regard on the arch. The aimpoint is the intended target's location at the time the decision was made to launch a Hellfire missile. When the field of regard is plotted, the aimpoint and the intended target's location will not be the same due to drift and target movement. If a possible target is acquired, the discrimination capability is used to determine if the target can be properly identified. Figure 9 shows the plotting of drift adjusted and non-drift adjusted fields of regard.

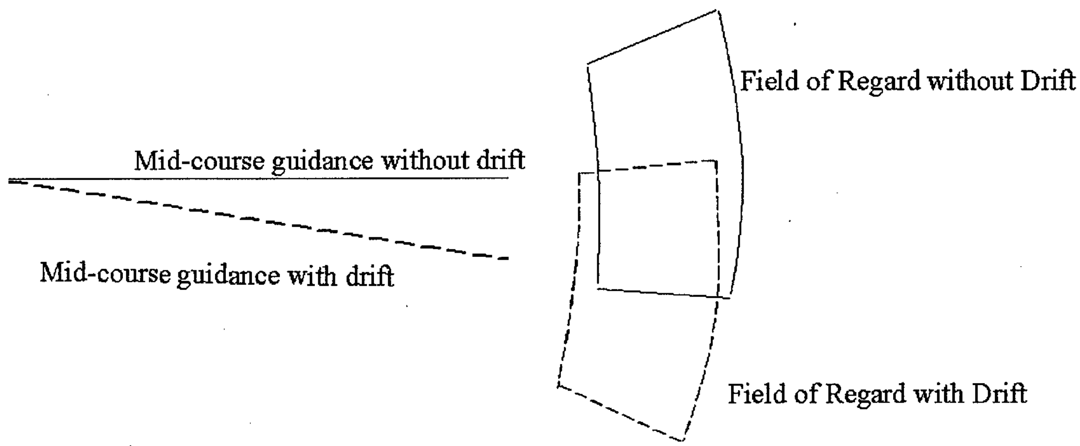

Figure 9. Application of drift Errors and Plotting the Field of Regard

Probability of hit (P-hit) tables are used if a target is identified. There are three tables, one for each of the seeker variants. Each table contains INU drift data and seeker specific data. The INU time independent data is expressed as a standard deviation measured in degrees and the time dependent drift is expressed as a standard deviation measured in degrees per second. A random number draw determines the magnitude of the time independent and time dependent drift. This assumes a standard normal distribution and is based on the empirical rule. The empirical rule states that 68% of all measurements are within one standard deviation of the mean, 95% will be within two standard deviations and 99.7% will be within three standard deviations of the mean

(Mendenhall and Sincich 1995). If a random draw number < 68 occurs for either of the drift components, the result will be a computer generated error less than 1-standard deviation based on a normal distribution. Since random draws occur for both the time dependent and time independent drift components of total drift, the probability of realizing a 1-standard deviation error for both components is .68 x .68 = .4624.

The main body of each P-hit table contains seeker specific probabilities of hit based on range, weather and target movement. This is mandated by the fact that the seekers have different performance based on weather conditions and whether the target is moving or stationary. After selecting the proper table, the system uses the P-hit and performs a random number draw to determine a hit or miss. If the outcome of a hit is determined, the system assesses the target vehicle's actions during the terminal guidance phase. Using the time of flight of the missile and the ground speed of the vehicle, we can determine the distance the vehicle moved during flight. Comparing the distance the target moved versus the ability of the missile to adjust during terminal guidance results in the assessment of a hit or miss. This is also weather related since greater adjustments can be made if the missile is further from the target when terminal guidance begins. The final variable considered in the determination of the hit is the employment of countermeasures. If the target vehicle moves into cover or employs a countermeasure, the determination of a hit is nullified.

Numerous errors associated with the detection of a target, computation of firing data and target hand-off are not considered in the new probability of hit method. This is due to the lack of valid data concerning these factors. If the factors can be quantified, they can be considered in the algorithm. This is accomplished by adding the errors at a

discrete point during the flight of the missile where they would normally be realized and adjusting the missile's position and behavior based on the errors. The target location error is directly related to the capabilities of the intelligence gathering device which initially detected the target. Data latency errors increase as the time interval between target detection and missile launch increases and add to the initial target location area. Relative geometry errors are a result of the launching platform not knowing the precise location of itself and the location of the target. They result in computational errors since an accurate firing solution is impossible if the start and end points are not precisely known. These errors were not considered since they are difficult to quantify and are outside the scope of this research.

3.4 Representing the Attributes as Behaviors in Constructive Simulation

The constructive simulation combines the effort of the previous steps and is the culmination to the task of determining how to replicate an advanced air-to-ground missile in a constructive simulation to facilitate multiple variant analysis. Validation of the procedure will be determined by subject matter experts and will be based on the simulation producing realistic results which meet a simulation goal. The simulation goal chosen for the evaluation is to determine the sensitivity of helicopter launched precision-guided missiles to the seeker configuration.

Three scenarios; deliberate attack, deep attack and area defense, were developed using ModSAF. In each scenario, AH-64D attack helicopters are used as the launching platform for one of three Hellfire III missile variants with a dual seeker. The three missile variants are SAL/Imaging Infra-red (SAL/IIR), SAL/Millimeter Wave

(SAL/MMW) and SAL/Laser Direction and Ranging (SAL/LADAR). All three Hellfire III missile variants have extended range capabilities that exceed the SAL and RF Hellfire missiles currently in service by seven kilometers. The three missile variants are compared in a head-to-head test using three scenarios. The scenarios are built on one of three terrain types listed in Table 7. The three-scenario concept was employed to ensure diversity and eliminate bias. To further increase validity, the research is designed, developed and executed while considering current attack helicopter operations in conjunction with ground maneuver operations, current threat doctrine, Army Vision 2010 and the Army Aviation Modernization Plan.

Table 7

Simulation Scenarios ,Terrain Types and Terrain Location

Scenario Name	Terrain Type	Terrain Location
Area Defense	Rolling hills	Fort Knox
Deliberate Attack	Desert	South west Asia
Deep attack	Mountainous	Bosnia

The measures of effectiveness are listed in Table 8 and are intended to measure the effectiveness of each seeker or reduce uncertainty of another metric. As an example, the number of enemy vehicles killed by Hellfire missiles will be used to assess the Loss Exchange Ratio (LER) and determine the overall effect of the Hellfire missile on the outcome of the battle. This is important since the LER is a result of kills by both ground

forces and Hellfire missiles. The number of vehicles killed by Hellfire missiles is also subject to scrutiny. The number of vehicles killed by Hellfire missiles is influenced by the number of Hellfire missiles that are launched and the number of Hellfire missiles that hit a target. The number of Hellfire hits must also be analyzed to determine the number of hits on intended targets.

Table 8

The Metrics and Their Scope

Metric	Scope
Loss Exchange Ratio (LER)	Measures performance of forces during complete battle
Assessed Value Ratio(AVR)	Measures the target elimination performance of the Hellfire missile
Hellfire Shots	Indicates the number of times a Hellfire missile was employed.
Hellfire Hits	Specifies the number of Hellfire missile that hit an enemy vehicle
Hellfire Hits on Intended Target	Specifies the number of Hellfire missile that hit the target at which it is was fired
Hellfire Kills	Provides a total number of enemy vehicles killed by Hellfire missiles
Redundant Hits	A measure of the number of targets that are attacked repeatedly
Helicopter Losses	The number of helicopters that are shot down by enemy forces during the battle
Ground Forces Kills	A total number of enemy vehicles killed by friendly ground vehicles

The loss exchange ratio (LER) is a calculation of the losses suffered by the friendly force (BlueFOR) while inflicting losses on the enemy force (RedFOR). The equation is:

$$LER = \frac{\text{RedFOR Vehicle Losses (Threat)}}{\text{BlueFOR Vehicle Losses (Friendly)}} \tag{9}$$

An LER above 1 indicates that the friendly force (BlueFOR) has destroyed more threat vehicles (RedFOR) than it has lost. Therefore, a larger LER value, the better the friendly forces are performing.

A variation of the LER is the assignment of values for varying degrees of damaged assessed by ModSAF. This method was developed specifically for this research and is referred to as the Assessed Value Ratio (AVR). After a target hit, the damage assessment process in ModSAF can result in the assessment of no damage, fire power kill, mobility kill, fire power and mobility kill or catastrophic kill. The damage to each vehicle increases with subsequent hits. Assigning values to different kills enables a more detailed assessment of the outcome of a battle. The point values assessed for each type of assessed damage are as follows:

Mobility Kill	1
Fire Power Kill	1
Mobility and fire power kill	2
Catastrophic kill	3

The AVR is a ratio between Red Force losses caused by Hellfire missiles and the number of Hellfire missiles fired. A large AVR indicates few redundant hits due to high damage assessments.

The equation is:

$$\mathrm{AVR} = \frac{\text{Red Force Losses Total Point Tally (Due to Hellfire)}}{(\text{Total Shots}) \text{ x } (\text{Maximum Value of a Shot})} \mathrm{X}\,100 \qquad (10)$$

Using the AVR, the contribution of each missile variant to the success of the Blue Forces during each scenario run can be assessed. This is accomplished by identifying the damaged caused by the advanced air-to-ground missile and converting it to a percentage of possible damage that could have resulted. The result is an indication of the missile's effectiveness despite variations between the simulation runs and a way to identify if the LER is skewed by the damage assessment process. The AVR is not biased by tactical considerations such as battle position location and enables the comparison of runs with and without advanced air-to-ground missiles. It is assumed that scenarios that result in greater Red Force losses due to advanced air-to-ground missiles will also result in greater Red Force losses due to Blue Ground Forces. This is because the Blue Ground Forces will have a force ratio advantage over the Red Force and therefore will be able to inflict heavier damage.

The number of Hellfire shots that occur, the number of Hellfire hits and the number of Hellfire hits on intended targets are used to discriminate between the performance of the various seeker heads. The hits on intended target metric is used to

assess target hits due to vehicle density and midcourse navigation errors. This is useful in eliminating luck from the assessment of seeker performance.

Statistical analysis of each metric will be accomplished through the comparison of means using a 95% confidence interval. To determine the minimum number of runs required to obtain valid data, 15 pilot runs will be conducted and the data for each metric analyzed. The value of 15 runs was selected based on a stability analysis conducted by Dr. Martin during previous simulation studies using ModSAF. The minimum number of study runs required will be computed using the following formula:

$$N2 = N1\left(\frac{H1}{H2}\right)^2 \tag{11}$$

N_1 = Number of Runs Completed (pilot runs)
N_2 = Number of Runs Completed which must be completed
H_1 = Confidence interval half-width of pilot runs
H_2 = Desired confidence interval half-width

It is assumed that the number of runs is sufficient for valid statistical analysis when the confidence interval half-width is less than 10% of the mean for each metric. Therefore, the H_2 value in the formula is obtained by multiplying the mean being assessed by .10. This process will be used to evaluate the number of runs required for each metric. The minimum number of required data producing runs is equal to number of runs of the metric which required the most runs to satisfy the requirement of the confidence interval being less than 10% of the mean.

The simulations were run on Silicon Graphics O2 computers connected together through a network. At least two machines were required during each run due to the size and large computational budget of the scenarios. The need to run multiple scenarios mandated the usage of a process that permitted the batch running of multiple scenarios. This also limited the scenario to scenario human-in-the-loop variability. At the conclusion of each scenario run, the data was stored to a file and the next run initiated. When all runs for the scenario were completed, the data was processed through a reaper that facilitated the collection of specific data on a wide array of simulation events. The events included entity to entity detection information, results of direct and indirect fire, and vehicle actions throughout the conduct of the simulation run. Advanced air-to-ground missile specific data which was captured during the simulations was the numbers of Hellfire missiles fired, the number of Hellfire missiles that hit targets, the number of helicopters lost and what shot down the helicopters that were lost. The data was evaluated and used to create the statistics for the metrics of interest. Initial analysis of the data was accomplished by transferring the data file over a network to a PC. The PC was used to put the data into Microsoft Excel and create charts. The data was also used with a replay tool that allowed the review and analysis of scenario runs for detailed observation of scenario events.

3.5 Scenario Summary

Scenario 1-Task Force (TF) Defense against an MRR:

This scenario, Figure 10, is based on an area defense mission and the AH-64Ds are used to attack the enemy in depth to separate the Forward Security Element (FSE)

and the Advanced Guard Main Body (AGMB). This scenario takes place on wooded terrain (FT Knox).

Friendly Force: A task force consisting of two mechanized heavy (mech heavy) companies (8 M2A3 and 4 M1A2) defends in sector to defeat the lead battalion of a Motorized Rifle Regiment (MRR) of the enemy attack. Two AH-64D platoons have an on order mission to conduct a mobile defense mission to support the ground forces defensive scheme. Four scout vehicles are positioned along the Forward Line of Troops (FLOT) in a screen line to gain and maintain contact with the enemy as they advance.

Enemy Force: A Motorized Rifle Regiment (-) attacks to defeat the TF and then pass the follow-on regiments. The MRR attacks with a lead Motorized Rifle Battalion of 10 T-80s and 23 BMP-3s. The MRB attacks in a standard advanced guard formation. A Combat Reconnaissance Patrol (CRP) of 3 BMPs is followed by a Forward security Element (FSE) of 4 BMPs and 3 T-80s. The CRP is approximately 5 kilometers ahead of the FSE. The Advanced Guard Main Body (AGMB), consisting of a tank company with 7 T-80 and 3 BMP-3s and a mechanized rifle company with 10 BMPs, trails the FSE by approximately 5 to 10 kilometers. Additionally, The AGMB has a 2S6 self-propelled air defense vehicle and 2 SA-16 air defense teams.

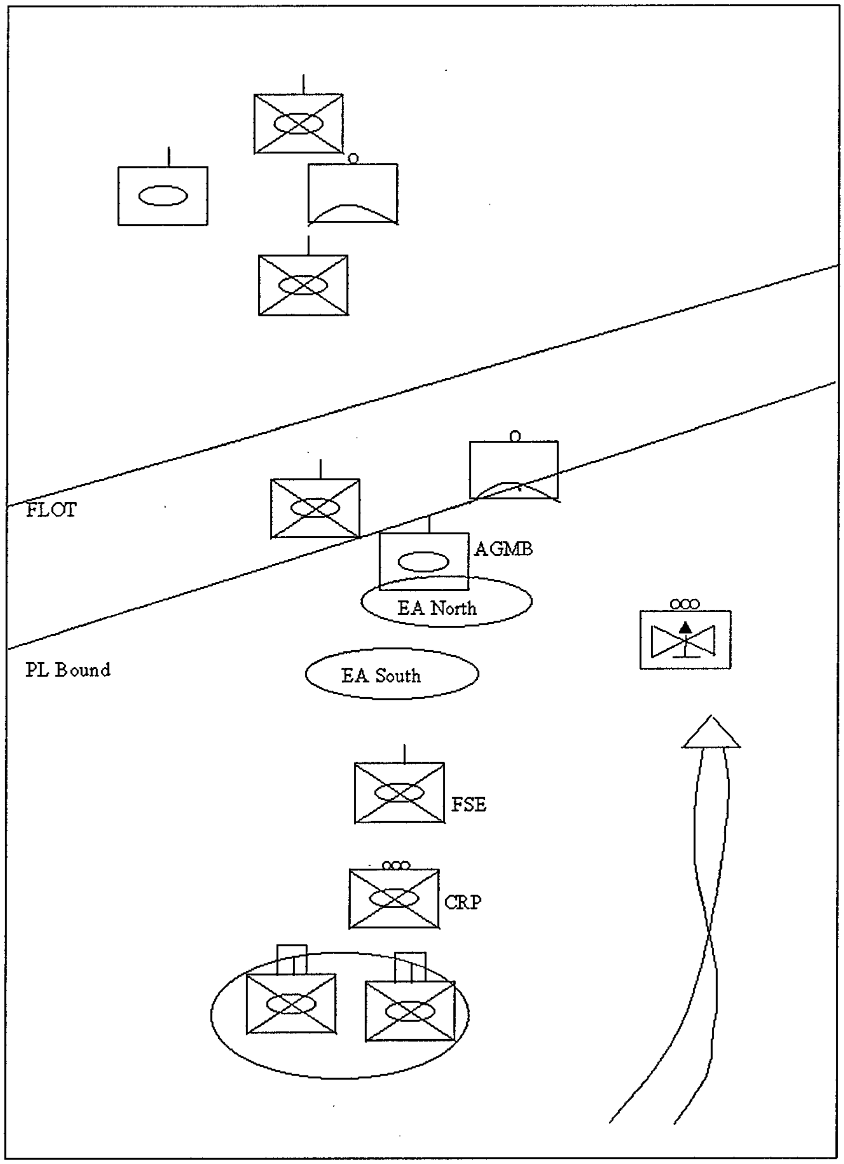

Figure 10. Task Force defense Against a Motorized Rifle Regiment (MRR)

Friendly Course of Action; The TF defends with two Mech. Infantry heavy teams (8M1A2s and 16 M2A3s) in a hasty battle position to defeat the lead MRB. The two AH-64D platoons are in a Forward Arming and Refueling Point (FARP) to the southeast of the infantry's defense. When signaled by the scouts that the AGMB is at the FLOT,

the first AH-64D platoon flies a route to the east of the main avenue of approach and occupies battle positions south of Phase Line (PL) Bound. When the AGMB enters the northern engagement area, the AH-64D platoon engages the Tank and BMP companies. The mission of the first platoon is to destroy the AGMB and so the infantry teams can fight an isolated FSE. When the lead company of the second battalion of the MRR reaches the FLOT, the second AH-64D platoon departs the FARP. The second platoon occupies battle positions south of the first platoon. The first platoon remains on station until the second platoon is on station and they are out of Hellfire missiles. The second platoon engages the second battalion in the southern engagement area.

Scenario 2-Task Force (TF) Attack:

This is a Blue TF attack against an enemy tank battalion at 50% strength (22 vehicles) in a desert environment (Figure 11). In this scenario, two AH-64D platoons are employed in an attack to attrit mission in support of the breach site.

Friendly Force: A balanced US TF (24 M1A2s and 24 M2A3s) attacks to seize the brigade's (BDEs) initial objectives, and then facilitate the passage of the remainder of the BDE.

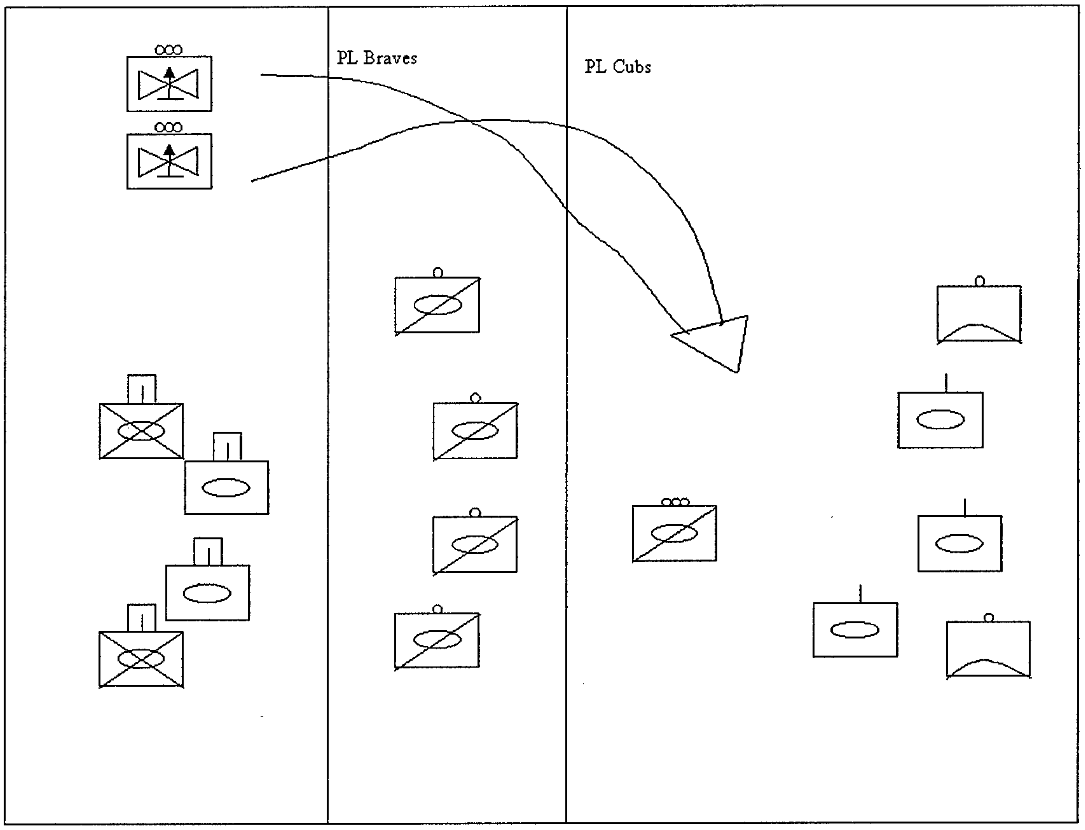

Figure 11. Task force Attack Against a Tank Battalion in Desert Terrain

Enemy Force: The enemy is a tank battalion at 50% strength. They are arrayed doctrinally in a prepared defense with a Regimental Recon section in sector of 1 BMP-3 and 1 BRDM-2, a Combat Security Outpost (CSOP) of 2 T-80Ums and 1 BMP-3, and a main defensive belt of 15 T-80Ums and 4 BMP-3s. The air defense weapons consist of two 2S6Ms and four SA-16 teams. The main belt is weighted in the south. The enemy has seven dismounted elements with ATGM in ambush positions. The enemy commander has also dispatched a tank platoon (3 T-80s) into a flank security mission who are also in a position to counterattack forces in the south. The enemy has dug in his CSOP and main defensive belt to hull defilade, and has placed 7 decoy vehicles amongst

his main belt position for deception. The enemy is supported by a battery of 8 2S1s (122mm self-propelled artillery pieces).

Friendly COAs: The attack begins with the scout platoon conducting a zone reconnaissance of the sector to destroy enemy recon and identify a weak point in the enemy's defense. When the scouts cross PL Brave, a tank heavy team, a mech heavy team and the first AH-64D platoon begin moving toward the objective. The AH-64Ds fly an ingress route along the northern flank of the ground maneuver units and take up battle positions west of the main defensive belt. They engage targets beginning in the north of the zone working south. The second AH-64D platoon launches when the scouts cross PL Cubs and flies the same route as the first platoon. The conduct a relief on station and continue engaging targets in the north to south manner.

Scenario 3: Deep Attack:

An enemy Motorized Rifle Division is staging for an attack within the next 24 to 48 hours (Figure 12). As part of a joint deep attack, an attack aviation company (8 AH-64Ds) conducts a deep attack against the Command, Control, Communication and Intelligence elements of the (C4I) and massed armor of the lead MRR. The scenario uses mountainous terrain (Bosnia).

F*riendly Force:* The friendly forces replicated in the simulation consist of 1 attack helicopter company.

Enemy Force: The RedFOR are in hasty defensive positions preparing to initiate an attack in the next 24 to 48 hours. They are at 95% strength and have a well developed air defense net. The Division Reconnaissance elements have penetrated the Bluefor area

and the regiment reconnaissance elements are up to 10 kilometers in front of the first echelon. A second echelon (notional) and reserves (notional) are positioned 30 to 50 kilometers behind the first echelon.

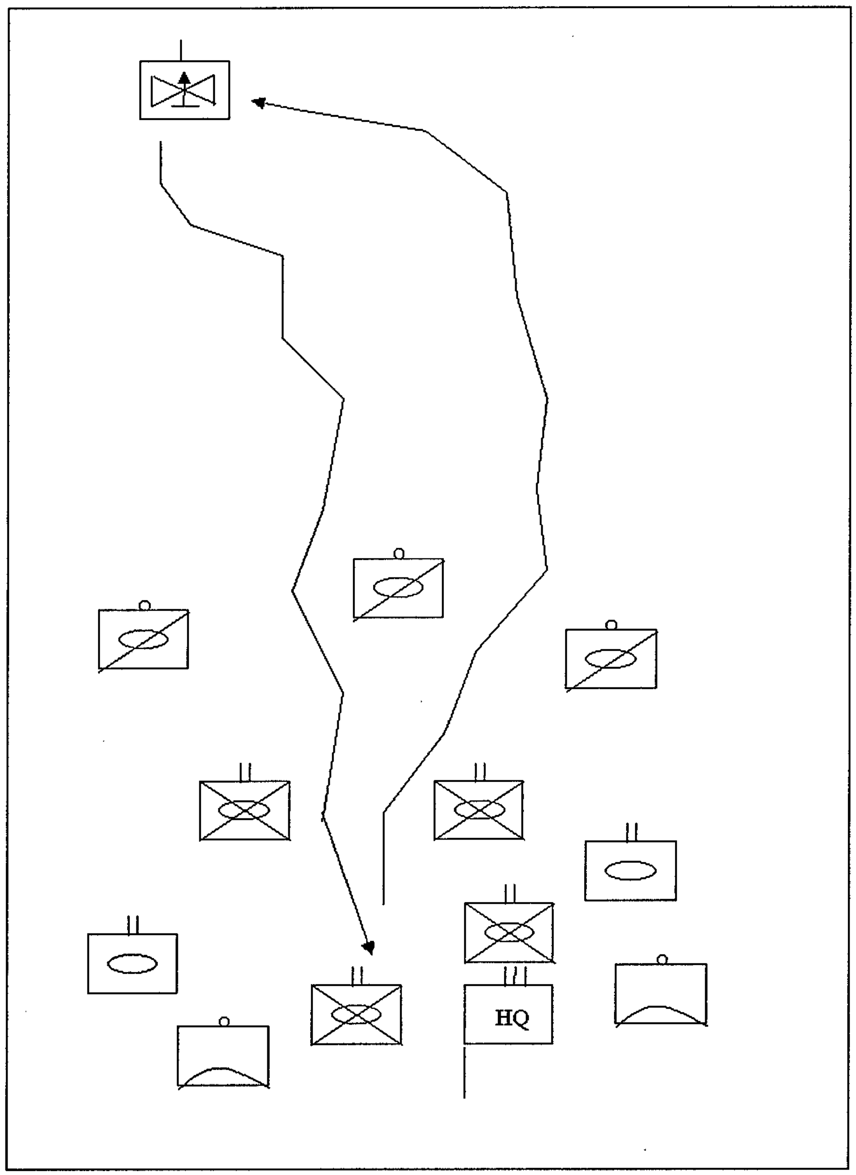

Figure 12. Deep Attack Against a Motorized Rifle Division (MRD)

Friendly COAs: The BlueFOR will conduct a joint deep attack against the first and second echelons to disrupt and disorganize the RedFOR. The AH-64D company will ingress using valleys for cover and concealment. They bypass lead elements and strike the C4I of the lead MRR. During egress, they attack massed armor and targets of opportunity.

3.6 Methodology and AMETA Algorithm Summary

The NETMOSA methodology introduced in this chapter is designed to identify future needs of the United States Army and provide a systematic process for determining how to best meet those needs. The methodology (Table 9) considers future weapons requirements, performance deficiencies of currently available weapon systems, technology that will mature during anticipated production periods and performance analysis based on constructive simulations.

Table 9

General Methodology

Process Steps	Input	Output	Tools
Need Identification	Army Modernization Plan	Future weapon requirements	Mission analysis
Current equipment evaluation	User community survey	Performance requirements and current system deficiencies	Survey
Technology Research	Technological literature	Feasible alternatives	
Build Constructive Model	Feasible alternatives	Constructive Model	Technology analysis
Scenario development	Doctrinal tactics, techniques and procedures	Functional scenarios	Army Operations Manuals
Analysis of output data	Data from Constructive Simulation runs	Decision Brief	Defined Metrics

The AMETA algorithm is an integral component of the constructive model and is a result of the need identification, current equipment evaluation and technology research conducted during the execution of the methodology. The AMETA algorithm is a new technique for implementing air-to-ground missiles in ModSAF but isn't a severe departure from conventional simulation procedures. Simply stated, the AMETA algorithm relies on discrete event simulation and the application of accumulated errors at the discrete events to replicate the flight profile of an air-to-ground missile. The magnitude of errors is determined by a table look-up based on a random draw. The error

tables and random draw probabilities are based on Lockheed Martin proprietary data. The benefit of the AMETA algorithm is that it facilitates realistic air-to-ground missile replication that is computationally inexpensive.

CHAPTER 4

CONDUCTING THE STUDY

4.1 Research Overview

The scope of this research was to explore the representation of air-to-ground missiles in ModSAF. The research was limited by money and time available. Therefore, the intent was to demonstrate the viability of the AMETA algorithm by developing a constructive model that enabled the representation of quantified missile behaviors. The goal of the research was to achieve internal validation of the model. This research did not account for all possible errors associated with the launch and subsequent flight of an air-to-ground missile. It is merely a starting point from which other researchers can proceed. Several identified errors not considered during this research are presented and discussed in Section 6.2.

A limited test was employed to determine if the research met the intent and goal. The metrics and scenarios described in Chapter 3 were essential to the test and provide insights to the validity of the AMETA algorithm. They permitted the development of the hypotheses that are introduced in Section 4.6 and are primarily directed at the evaluation of the variants. Expert opinion was employed as the primary method used to evaluate the AMETA algorithm. However, evaluation of the hypotheses was used as an additional means to determine if the entire model, including computer code, was functioning

properly. Internal validity was achieved but no external validity of model or AMETA algorithm is assumed.

4.2 Implementation of the Process

The first step in the NETMOSA methodology to be accomplished in this study was the current equipment evaluation. This step was to be accomplished through a survey of the user community and the outcome was to be the refinement of results determined by Dr. Martin from the first user community survey. This required the development of a new survey tool to investigate vague results and further clarify performance attributes the user community feels are important. During the research and development of the tool, it became apparent that an additional user community survey would have little value. This is primarily due to the vast differences between the current Hellfire missile and the Hellfire III missile which have opened a myriad of possible tactical employment options. The differences enable the Hellfire III missile to be utilized as an indirect fire weapon as well as a direct fire weapon.

Robert T. Gunning Jr. is a Retired Lieutenant Colonel that served as an Army Aviation Officer and Acquisition Corps Officer. He is currently employed by Lockheed Martin and provided invaluable insight as to the needs of the Army and the potential of the Hellfire III missile. As an experienced Aviation and Acquisition Corp Officer, he emphasized that the most important factor in determining performance attributes of the Hellfire III missile is the understanding of how the missiles will be used in conjunction with other future battle field assets. Since the user community does not have an appreciation of the tactical picture 10 years in the future, their opinions are only valid for

a small portion of the utilization spectrum. As he sees it, the future battlefield is less segmented and relies heavily on communications. Army Aviation will evolve from traditional missions and will acquire tasking that require versatility and speed to accomplish.

4.3 Technology Research

The outcome of the technology research is detailed in Chapter 3 and is a result of reviewing publicly available literature of the MMW, IIR and Ladar technologies. The seeker specific data detailed in Chapter 3 were provided by the Hellfire III project team at Lockheed Martin during a series of meetings and interviews. The technology information gleaned during the research facilitated the development of new Probability of hit (P-hit) tables for each seeker (Appendix A). The P-hit tables contain seeker specific information such as Horizontal Field Of View (HFOV), Vertical Field Of View (VFOV), time dependent inertial navigation unit drift, time independent inertial navigation unit drift, maximum terminal guidance range and probability of hit at incremental ranges. The P-hit tables are located in libbalgun and are used to determine the outcome of a target engagement based on weather, target movement and range to target.

The research was also focused to obtain an understanding of the events that occur during the time period between missile launch and target impact. This understanding led to the development of the AMETA algorithm. The AMETA algorithm is a logical procedure that considers events experienced during the flight of the missile and provides a method of applying quantifiable errors. The development of the AMETA algorithm provided the foundation for the development of the constructive model. A validation

process was used in conjunction with the development of the AMETA algorithm and the constructive model. The validation sequence is shown in Table 10. It is provided at this location to aid the reader by alleviating confusion associated with the implementation of the NETMOSA methodology.

Table 10

The Validation Process

	Components	Validated by	Methodology
AMETA algorithm	Algorithm logic P-hit tables	Hellfire III PM Senior Simulation Analyst	Expert opinion
Constructive model	Hellfire III missiles Computer code AH_64D_HFIII	Hellfire III PM Senior Simulation Analyst	Simplistic scenario output analysis
Scenarios	TF Defense scenario TF Attack scenario Deep attack scenario	Senior Simulation Analyst	Unit tasking synchronization analysis
Production runs	Simulation runs	Senior Simulation Analyst	Output data analysis

4.4 The Constructive Model

The constructive model was built using an iterative process. Once the algorithm was determined and validated, the model was constructed and tested to determine if the behaviors accurately reflected real life behaviors. The construction of the model involved the creation of computer code in various ModSAF libraries and the modification of several ModSAF reader files. Testing of the model required the creation of simplistic

scenarios that facilitated the detailed inspection of the models behaviors. Concurrent with this process, the missile behavior experts and programmers conducted periodic meetings to ensure that the computer programmers were capturing the salient performance characteristics of the missile. The periodic meetings were chaired by the senior simulation analyst and the Hellfire III project manager and were the foundation of the validation process of the constructive model. Errors and shortcomings addressed during the meetings were corrected by the programmer and tested.

The libprotocol, libdisconst, libphysdb, libattrdb, libdfdam and libbalgun libraries were modified to create the Hellfire III missiles. The general concept is that the Hellfire III missiles were defined in libprotocol and given a DIS compatible assignment in libdisconst. The missile launcher is defined in libphysdb and the aircraft weapons load is specified in libattrdb. When the missiles are fired, the hit tables located in libbalgun are used to determine if you hit the target. This appears to be a direct contradiction of the AMETA algorithm but is in actuality a programming process designed to reduce the workload of the processor. By determining the P-hit outcome first, missile launches that would end in a miss because the random draw resulted in a miss determination can be ended one step into the process. The missile is still represented on the GUI but will not hit a target and the spirit of the AMETA algorithm is not violated. If a hit is determined, the struck vehicle uses its dfdam mapping file to determine the extent of damage.

A Specialized AH-64D was created to serve as a launching platform for the Hellfire III missile and was denoted as the AH-64D_HFIII. This allowed the AH-64D to remain sterile and serve as the launching platform of the Longbow Hellfire missile. The AH-64D_HFIII was created by modifying the .rdr files of libunits, libpvd, libstdname,

models, modellist, libphysdb, libattrdb and libechelondb. The veh_type.cdf file of libprotocol was also modified and a parameters file for the AH-64D_HFIII was created. The Hellfire III missiles were listed under the AH-64D_HFIII parameters file so that they were recognized as components of the AH-64D_HFIII. The new vehicle was tested in simplistic scenarios to eliminate errors that occurred during the creation of the AH-64D_HFIII. Errors were detected by reviewing the parser as ModSAF loaded and evaluating the new aircraft as it performed assigned tasks and engaged a variety of enemy targets. Performance errors were tracked down and eliminated through the modification of the files that were used to create the AH-64D_HFIII.

The computer code function call for the AMETA algorithm is located in the libsrc directory in the bgun_shoot.c, bgun_prob.c, libbalgun.h and bgun_params.c files. These files rely on other functions and variables contained throughout the ModSAF structure to operate. The bgun_prob.c file contains the C code to determine current weather conditions, determine if the target is moving or stationary, and determine the P-hit table value. The bgun_shoot.c file augments the bgun_prob.c file and contains the C code to determine terminal guidance range, compute and apply total drift and determine the seeker field of regard.

The model was validated using two simplistic scenarios built with desert terrain. The validation was designed to ensure the code was performing correctly before attempting to run full scenario simulations. The first scenario consisted of an AH-64D_HFIII platoon against stationary targets. The second scenario pitted an AH-64D_HFIII platoon against moving targets. Both scenarios were run under moderate and adverse weather conditions and data were collected on the performance of each seeker.

Data were captured for analysis using a specialized charting function known as the Reaper. The Reaper is written in C code and is capable of manipulating the data stream generated during the running of a ModSAF scenario. The data stream is comprised of Protocol Data units (PDUs). A PDU is a Distributed Interactive Simulation (DIS) term for a unit of data that is passed on a network between simulation applications. The same data stream can be used to create a replay of the simulation run for analysis at above real time speeds.

The output from the Reaper was the Loss Exchange Ratio (LER), Hellfire kills, number of missiles fired, helicopter losses, blue force (friendly) losses and red force (enemy) losses. The LER is important to the determination of a seeker's effectiveness; however, it is not completely reliable with regards to Hellfire missile performance since the LER is a result of kills by both the helicopters and the ground forces. Therefore, the most reliable indication of a Hellfire III missile's performance is the total number of Hellfire III kills in each simulation run. Additionally, comparison of the total number of Hellfire III kills and total number of red Force (RedFOR) vehicles killed by blue force (BlueFOR) vehicles aides in determining the validity of the LER. The value of the LER cannot be discounted since a change in the LER gives system effect on the battle.

The output data from the validation scenarios were analyzed by Dr. Martin and compared to expected results. The expected results were derived from the analysis of the seeker fields of regard, weather performance data and terminal guidance range discussed in Chapter 3. Based on the analysis, it is reasonable to expect:

1. The MMW seeker will perform best against moving targets in moderate weather.
2. The MMW seeker will perform best against moving targets in adverse weather.

3. The IIR seeker will perform the best against stationary targets in moderate weather.
4. The IIR seeker will perform better than the Ladar seeker against moving targets in moderate weather.
5. The MMW seeker will perform the best against stationary targets in adverse weather but the performance will be less than the MMW seeker's performance against moving targets.

Following a batch of validation runs, the collected data were then transferred to a spreadsheet that was organized in a manner that facilitated analysis. The spreadsheet was generated using Microsoft Excel. Using the spreadsheet, it was easy to compare the results of a seeker employed in adverse weather to the same seeker employed in moderate weather. It was also easy to compare the results of all seekers in a certain weather condition. If the results were different than expected, an attempt was made to identify the root cause of the error. Print statements were added to the code to determine when functions were being called and the output from the function. Also, the debug function of ModSAF was used to determine the information being supplied by the ModSAF libraries. This resulted in the determination that the cause was either with the computer code or the ModSAF libraries. Based on the analysis, the code or the library files were modified and the process resumed at the beginning of the model validation loop.

This procedure was used successfully with the implementation of the seeker field of regard. The code was modified in a manner that resulted in the plotting of the field of regard on the GUI. Therefore it was possible to view a validation run and compare the field of regard appearance and location to what was anticipated. Code was also created that resulted in the marking of the drift-adjusted aimpoint and targets that were located in the field of regard. For each Hellfire missile launched, print statements allowed the viewing of the terminal guidance range, the selected P-hit table value, the random draw

result and the hit or miss determination. The significant value of the procedure is that it is easy to verify if the computer is doing what is desired. If the code is working as designed but problems exist, then the design is flawed.

4.5 Running the Simulation

The scenarios, as described in Chapter 3 were built using information from US Army Field Manuals (FM) and operational documents that included:

1. FM 1-112, Attack Helicopter Operations
2. FM 100-5, Operations
3. FM 101-5-1, Operational Terms and Symbols
4. FM 100-2-1, The Soviet Army: Operations and Tactics
5. FM 100-2-2, The Soviet Army: Specialized Warfare and Rear Area Support
6. FM 100-2-3, The Soviet Army: Troops, Organization and Equipment

The steps involved developing over-lay graphics, creating specialized units, plotting the units, assigning unit taskings and synchronizing unit movement through the use of a scenario validation loop. Synchronization of unit movement was done to ensure the engagements occurred in accordance with a feasible battle plan to facilitate realism. This was accomplished by running the simulation and evaluating the position of the units at critical points in time. The unit taskings were then adjusted until the units met at designated engagement areas. When the random, haphazardness of the battle was removed from the scenarios, the simulations were documented and run using the validated model based on the AMETA algorithm.

Documentation involved the creation of overlay files, unit location text files and execution matrices. The overlay files contain all of the overlay graphics of a scenario. All of the graphics created for a scenario are used to control the movement of the entities within the scenario. The text files define the various units and initial positions at the start-up of the scenario. They were generated using a text editor and can be read directly into a ModSAF scenario. The execution matrices of the scenarios were replicated through the use of Microsoft Excel. The flexibility of Excel allowed the capturing of the unit tasking information in a format the closely resembles the GUI execution matrices found in ModSAF. The documentation enabled the quick and efficient regeneration of a scenario without the use of the Graphical User Interface (GUI) except for the recreation of the execution matrices. If a scenario becomes contaminated, the overlay file and text file are read into ModSAF to plot graphics and units. The execution matrices are then manually created using the Excel spreadsheets and the ModSAF GUI.

The simulation runs of the current Hellfire missile, the Longbow Hellfire, used slightly modified scenarios to compensate for the difference in maximum range between the Hellfire III missile and the Longbow Hellfire missile. Since the maximum range of the Longbow Hellfire missile is approximately half the distance of the Hellfire III missile, the battle positions used with the Longbow Hellfire missile were much closer to the engagement areas. This resulted in the expectation that:

1. More Longbow Hellfire missile equipped helicopters would be shot down than Hellfire III equipped helicopters since they had to be within the effective range of the enemy air defense units to attack targets in the engagement areas.
2. The longbow Hellfire missile would be less effective than the MMW missile due to the range limitations. Since the maximum range is significantly shorter, less area can be covered; therefore, fewer targets will be engaged.

Production runs were accomplished through the use of script files (Appendix B). The script files are located in the ModSAF directory and are comprised of the instructions required to conduct multiple runs using all seeker types and both moderate and adverse weather. The script file states the terrain data, the seeker type and weather type to be used during the production run. It also states the number of production runs to be accomplished and defines the name and location of the output data from the production runs. The script files reference batchsource files during execution. The batchsource files define the scenario to be used and the length of time the scenario will run. Once a script file is initiated, the computer executes the instructions in the file until the end of the script is reached or the process is manually interrupted.

The first step in the execution of the script was the clearing of the data collection file through the use of a remove command. This removed the files in the data collection directory and prevented the output data from becoming contaminated by previous simulation runs. The desired weather and seeker information was then copied directly into the data file from the libattrdb and libvisual reader files. There were three libattrdb reader files, one for each of the three Hellfire III missiles, and two libvisual, one for moderate and one for adverse weather created to facilitate the process. By coping the reader files directly into the data directory, the need to do a gmake was eliminated. Once the seeker and weather combination were set, the script loaded ModSAF and then caused the batchsource file to load the scenario. At the end of the simulation run, the data is sent to the file defined in the script and another run is initiated until the specified number of runs for the seeker/weather combination is met. When the specified number of runs is completed, the reader files of the next specified seeker/weather combination are loaded

into the data directory and the desired number of simulation runs are completed. This process continues until the end of the script file is reached. The output data from the simulation is accessed by opening the directory that contains the data as specified in the script file. This process allows the accomplishment of production runs without a human in the loop. Typical production runs were accomplished using script files that were approximately 100 hours in length. The number of production runs accomplished during the 100-hour period was dependent upon the length of the scenarios. If the scenario required 3 hours to run, 33 runs were scheduled using the various seeker/weather combinations. Only one of the eight various seeker/weather combinations (MMW/adverse, IIR/moderate, etc.) was employed during each of the production runs.

Prior to the production runs, the ModSAF code was modified to facilitate the collection of specific data required to enable the use of several of the metrics defined in Chapter 3. The data included the intended target identification number, target type, range to target, engagement outcome (hit/miss), vehicle identification number if hit occurred, assessed damage and total drift applied. The data was not required prior to this point since the focus was on the model performing correctly, not on the performance comparison of the seekers. The code modifications permitted the post processor, known as the Reaper, to gather required data. Following a production run, the Reaper was used to process the data for analysis. The Reaper is a charting program that is written in C code and is capable of manipulating the data stream generated during the running of a ModSAF scenario. The Reaper uses a script file that defines the scenarios that will be processed. Similar seeker/weather combination production runs are grouped together and then compared to a group of other seeker/weather production runs. Multiple groups can

be constructed and there can be numerous simulation runs inside of each group. The output from the Reaper is the performance metrics or data required to determine the performance metrics as defined in Chapter 3. The output is in the form of individual averages of the measured parameters for each production run in a group and a group average for each parameter. This facilitates future analysis using the individual data points. The output data from the Reaper uses the text file format and was transferred over a Local Area Net (LAN) to a desktop PC. The PC was used to organize the data on an Excel generated spreadsheet that contained the following columns:

1. Seeker/weather combination
2. Loss Exchange Ratio (LER)
3. Hellfire Kills
    - BMP-3s Killed
    - T80UMs Killed
    - 2S6Ms Killed
    - Total Hellfire Kills
4. Hellfire Missiles Fired
5. Helicopters Shot Down by Enemy (Redfor)
6. Bluefor Ground Kills (enemy killed by Bluefor vehicles)
    - M1A2
    - M2A3
7. Losses
    - Bluefor vehicles killed by enemy
    - M1A2s Killed by Redfor
    - M2A3s Killed by Redfor
    - Redfor vehicles Killed by Bluefor

The production run validation loop is very similar to the model validation and scenario validation loops. Dr. Martin analyzed the output data from the Reaper after it was transferred to the spreadsheet. This involved the comparison of the results from the simulation runs to the expected results based on the analysis of the data used to construct the model. If a metric appeared to posses erroneous data, the validity of the output data

was evaluated to determine if it was a logical result based on the data used to construct the model. If output data were determined to be erroneous, possible causes were identified and the ModSAF files inspected. A replay tool was often used to confirm or deny suspicions about events that occurred in the simulation. The replay tool is written in C code and permits the viewing of a simulation run at speeds that vary from real time to above real time. Using the tool, simulation runs approximately 3-hours in length can be reviewed in less than 7 minutes and individual events can be isolated. The replay tool uses the same PDU based data stream as the Reaper. Therefore, there is a direct relationship between what is seen during the replays and the output data from the Reaper. Once the causes of errors are identified and corrected, the simulation validation loop was completed by running the production runs and evaluating the output data to determine if the errors are eliminated.

4.6 Hypothesis Development and Analysis

The hypotheses identified for this research are based on the anticipated performance results detailed in Sections 4.3 and 4.4 and are designed to assist in the assessment of internal validity of the model. They are integral to the analysis plan, Figure 12, and were developed to determine if differences exist between the three variants of the Hellfire III missile, as well as to investigate the possible existence of differences between the Longbow Hellfire missile and the Hellfire III missile variants.

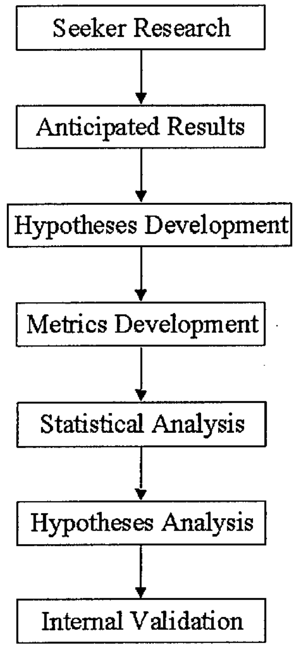

Figure 13. Simulation Production Run Analysis Plan

The hypotheses were designed for a specific purpose and the metrics designed so that they supported the evaluation of the hypotheses. There are two sets of hypotheses and the metrics associated with the hypotheses are defined and described in Section 3.4. The first set is applicable to the evaluation of the Hellfire III missile variants and the second set was created for the comparison of the Longbow missile and the Hellfire III variants. The hypotheses developed for the evaluation of the three Hellfire III variants are contained in Table 11. They facilitate the comparison of the MMW, IIR and Ladar missiles in both moderate and adverse weather conditions.

Table 11

Hellfire III Variant Comparison Hypotheses

	Adverse Weather	Moderate Weather
Loss Exchange Ratio (LER)	H_0: MMW $\bar{y}$ = IIR $\bar{y}$ = Ladar $\bar{y}$	H_0: MMW $\bar{y}$ = IIR $\bar{y}$ = Ladar $\bar{y}$
	H_A: MMW $\bar{y}$ > IIR $\bar{y}$ ≠ Ladar $\bar{y}$	H_A: MMW $\bar{y}$ ≠ IIR $\bar{y}$ ≠ Ladar $\bar{y}$
Hellfire Hits	H_0: MMW $\bar{y}$ = IIR $\bar{y}$ = Ladar $\bar{y}$	H_0: MMW $\bar{y}$ = IIR $\bar{y}$ = Ladar $\bar{y}$
	H_A: MMW $\bar{y}$ > IIR $\bar{y}$ ≠ Ladar $\bar{y}$	H_A: MMW $\bar{y}$ ≠ IIR $\bar{y}$ ≠ Ladar $\bar{y}$
Hellfire Hits on Intended Target	H_0: MMW $\bar{y}$ = IIR $\bar{y}$ = Ladar $\bar{y}$	H_0: MMW $\bar{y}$ = IIR $\bar{y}$ = Ladar $\bar{y}$
	H_A: MMW $\bar{y}$ > IIR $\bar{y}$ ≠ Ladar $\bar{y}$	H_A: MMW $\bar{y}$ ≠ IIR $\bar{y}$ ≠ Ladar $\bar{y}$
Assessed Value Ration (AVR)	H_0: MMW $\bar{y}$ = IIR $\bar{y}$ = Ladar $\bar{y}$	H_0: MMW $\bar{y}$ = IIR $\bar{y}$ = Ladar $\bar{y}$
	H_A: MMW $\bar{y}$ > IIR $\bar{y}$ ≠ Ladar $\bar{y}$	H_A: MMW $\bar{y}$ ≠ IIR $\bar{y}$ ≠ Ladar $\bar{y}$

The Longbow Hellfire missile and Hellfire III missile variant comparison hypotheses are contained in Table 12. The hypotheses facilitate the comparison of the Hellfire III missile variants and the Longbow Hellfire missile in both moderate and adverse weather conditions. The two sets of hypotheses differ because the implementation methods of the Longbow Hellfire missile and Hellfire III missile variants in ModSAF are vastly different. Therefore, the same metrics cannot be employed since the Longbow Hellfire targeting process does not support all the metrics as the Hellfire III missile variants. As an example, the hits on intended target metric cannot be used to evaluate the Longbow Hellfire since ModSAF does not include provision for hitting any target with the Longbow Hellfire missile other than the one which was targeted.

Table 12

Longbow Hellfire versus Hellfire III Comparison Hypotheses

Metric	Hypotheses
Loss Exchange Ratio (LER)	H_0: Hellfire III $\bar{y}$ = Longbow Hellfire $\bar{y}$ H_A: Hellfire III $\bar{y}$ > Longbow Hellfire $\bar{y}$
Hellfire Shots	H_0: Hellfire III $\bar{y}$ = Longbow Hellfire $\bar{y}$ H_A: Hellfire III $\bar{y}$ > Longbow Hellfire $\bar{y}$
Hellfire Kills	H_0: Hellfire III $\bar{y}$ = Longbow Hellfire $\bar{y}$ H_A: Hellfire III $\bar{y}$ > Longbow Hellfire $\bar{y}$
Helicopter Losses	H_0: Hellfire III $\bar{y}$ = Longbow Hellfire $\bar{y}$ H_A: Hellfire III $\bar{y}$ < Longbow Hellfire $\bar{y}$

The number of productions runs required to obtain valid results was determined as described in Section 3.4. The confidence interval of the three Hellfire III seekers, in each of four metrics chosen for comparison in both weather conditions were determined. The most runs required for a seeker/weather/metric combination to achieve the goal of the confidence interval half-width not larger than 10% of the mean was determined to be the minimum number of production runs required for the Hellfire III seeker/weather combinations. The same process was also used to determine the minimum number of

production runs required to analyze the Hellfire Longbow and Hellfire III comparison metrics.

The analysis of the various Hellfire missiles is a two step process. Each step is comprised of a Part A and a Part B. In each step, Part A is focused on comparing the Hellfire III missile variants to one another and Part B is concerned with the comparison of the Longbow Hellfire missile to the Hellfire III missile variants. Part A uses the metrics and hypotheses listed in Table 11 and Part B uses the metrics and hypotheses listed in Table 12. The two step process was chosen to reduce the complexity of the analysis while providing increased visibility of subtle performance characteristics. The fist step is the normalized comparison of the Hellfire missiles for each metric. The second step is the proving/disproving of the hypotheses based on the comparison of mean values to a .95 confidence interval generated for all of the metrics listed in Tables 11 and 12 in both moderate and adverse weather conditions. The 95% confidence interval is derived through the use of a t test since the number of production runs is less than 30. The MMW seeker serves as the baseline for all metrics in both moderate and adverse weather conditions. The mean values for each of the various seeker/weather combinations are then compared to the MMW seeker .95 confidence interval developed for the same weather condition.

The mean value for all metrics of the various seeker/weather combinations was determined when the production runs were completed and then stored in a text file. The Reaper performed this function in addition to organizing the data of the individual runs. The t distribution was determined by pulling the data of the Hellfire III MMW individual runs from the text file and entering it on an Excel spreadsheet where it was processed

through the use of the data analysis tools. This facilitated the process of proving/disproving the hypotheses which relies on the following metric/t test relationships:

Loss Exchange Ratio, Hellfire Hits, Hellfire Hits on Intended Target and Assessed Value Ratio:

a. Two-tail test for Hellfire III MMW versus Hellfire III MMW Ladar in adverse weather
b. One-tail test for Hellfire III MMW versus Hellfire III IIR in adverse weather.
c. Two-tail test for comparison of all Hellfire III variants in moderate weather.
d. One-tail test for Hellfire III variants versus Longbow Hellfire.

Hellfire Shots, Hellfire Kills and Helicopter Losses:

One-tail for Hellfire III variants versus Longbow Hellfire.

The analysis of the output data from each scenario using the metrics is designed to provide insight into the value of the AMETA algorithm as well as validity to the constructive model and P-hit tables. All elements were validated individually but the interaction of the components can only be assessed by executing the entire process. The AMETA algorithm was validated through the use of expert opinion as described in Section 4.2. However, the value of the algorithm could not be ascertained by simply validating that the structure logically facilitated accurate replication of air-to-ground missiles. Therefore, it is essential to analyze the output generated from the interaction of all components to determine internal validity and the value of the AMETA algorithm.

CHAPTER 5

DATA PRESENTATION AND ANALYSIS

5.1 Chapter Overview

The analysis of the data is presented in this chapter with consideration to both practical significance and statistical significance. Practical significance is as important to statistical significance since the statistical significance can be skewed by a simple alteration to the force mix such as adding additional threat entities. The data is presented in a sterilized form to prevent the disclosure of Lockheed Martin proprietary data but the analysis is based on the raw data from the simulation runs.

A potential area of confusion is centered on the comparison of Hellfire hits and Hellfire kills. Hellfire kills are based on target damage assessed through the use of Army Material System Analysis Activity (AMSAA) data. The data is imbedded in the dfdam library of ModSAF and was not altered for this research. When a Hellfire missile hits a target, ModSAF determines the extent of the damage and produces a result of no damage, fire power damage, mobility damage, fire power and mobility damage or catastrophic damage. For this research, a Hellfire kill was assumed if a result of fire power and mobility damage or catastrophic damage was assessed.

A common trend noticed during the research was that the Hellfire III missile variants usually (98%) hit the intended target. This implies that drift is irrelevant. Drift does have the potential to influence the outcome as shown in Table 5 and discussed in Section 3.3; however, the potential influence is small. Additionally, the two components of drift appear to be neutralizing one another during at least 50% of the Hellfire engagements due to the random draw process (Table 13). The confluence of these two facts, small potential influence and neutralization due to random draw process, seems to have minimized the effect of drift on the outcome of the Hellfire engagements replicated in this research.

Table 13
Probability of Drift Neutralization Due to Random Draw

Time Dependent	Probability	Time Independent	Probability	Probability of Both Occurring
Left	.5	Left	.5	.25
Left	.5	Right	.5	.25
Right	.5	Left	.5	.25
Right	.5	Right	.5	.25

There are four possible directional outcomes for the representation of drift for each Hellfire engagement as shown in Table 13. Due to the random draw process, the time dependent drift component may be assigned a left drift adjustment and the time independent component may be assigned a right drift adjustment. The outcome is the significantly reduced effect of drift. Whether or not this phenomenon is a true representation of reality is beyond the scope of this research. Additionally, the seeker

fields of regard half-widths (Section 3.3), with the exception of the Ladar/stationary target/adverse weather, are larger than the maximum sum of a 1-standard deviation error in both time independent and time dependent drift. Therefore, drift by itself did not significantly influence the outcome of the Hellfire engagements represented in ModSAF during this research.

A problem noticed during data analysis is that although enemy air defense units were in close proximity to helicopter units occasionally, they did not engage the helicopters during any of the simulation runs. As a result, no data was collected concerning the influence that enemy air defense systems have on the outcome of the simulation runs. Therefore, "N/A" was entered in the Helicopter losses metric rows of the data tables. Based on analysis conducted to develop the hypotheses used during the research, it was anticipated that helicopters firing the Longbow Hellfire would be shot down since their battle positions were within the maximum effective range on the enemy air defense weapons. The location of the battle positions was mandated by the maximum range capability of the Longbow Hellfire missile. The scenarios were initially built using ModSAF version 3.0 and the anticipated results were confirmed during validation. However, the production runs were accomplished using ModSAF version 4.0 and some unanticipated events occurred. Since the Air Defense units were not functioning properly, this analysis shows the results of the representations of the scenarios and the flight algorithm. The effects of the longer stand-off range are not shown. The situation and possible causes are discussed further in section 5.5.

5.2 Task Force Defense

The Task Force Defense scenario pits two Mechanized Heavy Infantry Companies against two battalions of a Motorized Rifle Regiment (MRR). The infantry companies are augmented with two tank platoons, four scout vehicles and two platoons of AH64D_HFIIIs. As the lead battalion of the MRR advances in the standard Advance Guard formation, the first AH-64D_HFIII Platoon conducts a Hasty Attack of the Advance Guard Main body. The intent is to separate the Advance Guard Main Body (AGMB) from the Combat Reconnaissance Patrol (CRP) and Forward Security Element (FSE). Therefore, the Mechanized Heavy Infantry Companies will only fight the CRP and FSE. After engaging the AGMB, the first AH-64D_HFIII Platoon conducts a Screen. The second AH_64D_HFIII Platoon launches as the second battalion of the MRR advances and conducts a Hasty Attack. The intent is to delay, disrupt and disorganize the enemy. This allows the Mechanized Heavy Infantry Companies to finish the fight with the FSE and CRP prior to engaging a depleted battalion. The normalized output data for the TF Defense scenario is contained in Tables 14 and 15. Table 16 contains the confidence interval comparison results and Tables 17 and 18 are the results of the hypotheses proving/disproving for the Task Force Defense scenario.

Table 14

Normalized Comparison of Hellfire III Variant Performance for the Task Force Defense Scenario

	Moderate			Adverse		
	MMW	IIR	Ladar	MMW	IIR	Ladar
LER	1.0	1.043	1.286	1.0	0.938	0.983
Hellfire Hits (HH)	1.0	0.838	0.964	1.0	0.729	0.809
HH on Intended Targets	1.0	0.832	0.951	1.0	0.719	0.803
AVR	1.0	0.867	1.268	1.0	0.867	1.214

5.2.1 Practical Significance

The capabilities of the Hellfire III variants enabled the placement of battle positions at distances safe from the enemy air defense assets while allowing maximum coverage of the enemy avenues of approach. The AH-64D_HFIII Platoons hit the advancing enemy at critical points and disrupted the attack by separating the elements. The enemy's plan was to conduct a synchronized, in-depth attack. The enemy attacks in depth for the purpose of maintaining flexibility within their offensive operations. Areas of success can be exploited and strong defenses can be avoided. By attacking the enemy in the manner used in the scenario, the enemy's flexibility is reduced and the defending ground force maintains numerical superiority. Additionally, the defending ground force acquires valuable insight of the enemy's intent and maintains freedom of maneuver.

Table 15

Normalized Numerical Comparison of Hellfire Longbow and Hellfire III Variant Performance for the Task Force Defense Scenario

	Moderate				Adverse			
	Longbow	MMW	IIR	Ladar	LongBow	MMW	IIR	Ladar
LER	0.652	1.0	1.043	1.286	0.525	1.0	0.938	0.983
Hellfire Shots	0.311	1.0	1.003	1.108	0.308	1.0	0.995	0.802
Hellfire Kills	0.609	1.0	1.043	1.286	0.509	1.0	0.954	1.0
Helo Losses	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

In this scenario, fewer Hellfire missiles are launched than in the TF Attack and Deep Attack scenarios. The reduced number of shots is due to the rolling terrain on which the scenario is run. During the scenario, potential targets were able to conceal themselves from observation and maneuver past the AH-64D_HFIII Platoons without being engaged. A second interesting fact is that the raw data results of the Task Force Defense scenario had the most variation in the mean values of the metrics for each of the seeker/weather combinations. Two factors, simulation complexity and simulation duration, may be responsible for the increased variability. Each run of the scenario was 3 hours in length and involved over 20 synchronized events. As a result, some erratic entity behaviors may have occurred.

Table 16

Confidence Interval Comparison for Task Force defense Scenario

	IIR	Ladar	Longbow
LER/MMW/Moderate	Within CI	Outside (high) CI	Outside (low) CI
LER/MMW/Adverse	Within CI	Within CI	Outside (low) CI
HF Hits/MMW/Moderate	Within CI	Within CI	N/A
HF Hits/MMW/Adverse	Outside (low) CI	Outside (low) CI	N/A
Intended Tgt/MMW/Moderate	Within CI	Within CI	N/A
Intended Tgt/MMW/Adverse	Outside (low) CI	Outside (low) CI	N/A
AVR/MMW/Moderate	Within CI	Outside (high) CI	N/A
AVR/MMW/Adverse	Outside (low) CI	Outside (high) CI	N/A
HF Shots/MMW/Moderate	Within CI	Outside (high) CI	Outside (low) CI
HF Shots/MMW/Adverse	Within CI	Outside (low) CI	Outside (low) CI
HF Kills/MMW/Moderate	Within CI	Outside (high) CI	Outside (low) CI
HF Kills/MMW/Adverse	Within CI	Within CI	Outside (low) CI
Helo Losses/MMW/Moderate	N/A	N/A	N/A
Helo Losses/MMW/Adverse	N/A	N/A	N/A

5.2.2 Statistical Significance

Although the Hellfire III Ladar mean values for Hellfire shots and Hellfire hits in adverse weather are outside the lower boundary of the confidence interval (Table 16), the Hellfire III Ladar mean value for LER in adverse weather is inside the Hellfire III MMW adverse weather confidence interval (Table 16). This is a result of the adverse weather

Hellfire III mean value for AVR being above the confidence interval and dragging the LER into the confidence interval. AVR is a measure of the influence that the damage assessment process has on the determination of the Hellfire kills and LER metrics. The AVR is directly related to Hellfire kills and LER and will skew the Hellfire kills and LER metric if it is not in the confidence interval for the seeker/weather being evaluated. Tables 14 and 15 show that despite 20% fewer shots taken and 20% fewer hits, the Hellfire III Ladar mean LER value in adverse weather was nearly identical to the Hellfire III MMW.

Table 16 shows that the mean values for the moderate weather Hellfire III Ladar metrics with the exception of Hellfire hits and Hits on intended target are above the Hellfire III MMW confidence interval. Despite the number of shots taken being above normal, the number of hits realized is within the normal range. This appears to a normal reflection of the random draw process. The fact that the moderate weather Hellfire III Ladar LER is above normal despite normal hits is related to the fact that the moderate weather Hellfire III Ladar AVR is above normal. Although an average number of shots were recorded, the damage assessed against the targets that were hit was above the moderate Hellfire III MMW baseline information. Therefore, the moderate weather Hellfire III Ladar LER was above normal.

Table 17

Hellfire III Variant Hypothesis Evaluation

	Result	Reason
LER/Moderate	Null Rejected	Ladar mean outside upper boundary of MMW CI
LER/Adverse	Null Accepted	Both IIR and Ladar means within MMW CI
HF Hits/Moderate	Null Accepted	Both IIR and Ladar means within MMW CI
HF Hits/Adverse	Null Rejected	Both IIR and Ladar means outside lower boundary of MMW CI
Hit on intended Target/Moderate	Null Accepted	Both IIR and Ladar means within MMW CI
Hit on intended Target/Adverse	Null Rejected	Both IIR and Ladar means outside lower boundary of MMW CI
AVR/Moderate	Null Rejected	Ladar mean outside upper boundary of MMW CI
AVR/Adverse	Null Rejected	IIR mean outside lower boundary and Ladar mean outside upper boundary of MMW CI

Tables 14, 15 and 17 show that there is relative parity between the Hellfire III MMW and IIR seekers when employed in moderate weather since the mean values for all of the metrics in moderate weather are not statistically different. Table 17 also shows that the mean values of the metrics for Hellfire III IIR missile in adverse weather with the exception of the AVR, Hellfire hits and Hellfire Hits on intended target are not statistically different from the mean values of the Hellfire III MMW. Closer inspection of the adverse weather Hellfire hits metric listed in Table 14 indicates that the Hellfire III IIR realized 27% fewer hits than the Hellfire III MMW. Additionally, the Hellfire III IIR

AVR was 13% below the Hellfire III MMW. These facts cast doubt on the validity of the Hellfire III LER since they are both below the Hellfire III MMW confidence interval. Analysis of the raw data indicates that there approximately ½ fewer Hellfire engagements in the Task Force Defense scenario than in either the Task Force Attack or Deep Attack scenarios. As mentioned previously, the Task Force Defense scenario also has the greatest variability in the average values of the metrics for the three scenarios. Since there are fewer Hellfire engagements and greater variability, the LER is small with a wide confidence interval. The result is that the LER mean value for the adverse weather Hellfire III IIR is within the confidence interval even though the Hellfire hits and AVR metrics contradict the results.

Table 18

Hellfire III Variant versus Longbow Hellfire Hypothesis Evaluation

	Result	Reason
LER/Moderate	Null Rejected	Longbow Hellfire mean outside lower boundary of MMW CI
LER/Adverse	Null Rejected	Longbow Hellfire mean outside lower boundary of MMW CI
HF Shots/Moderate	Null Rejected	Longbow Hellfire mean outside lower boundary MMW CI
HF Shots/Adverse	Null Rejected	Longbow Hellfire mean outside lower boundary MMW CI
HF Kills/Moderate	Null Rejected	Longbow Hellfire mean outside lower boundary MMW CI
HF Kills/Adverse	Null Rejected	Longbow Hellfire mean outside lower boundary MMW CI
Helicopter Losses/Moderate	N/A	N/A
Helicopter Losses/Adverse	N/A	N/A

The results in Table 18 are not surprising and indicate that the performance of the Hellfire III variants exceeds the performance of the Longbow Hellfire. The Longbow Hellfire III engagement areas were restricted by the maximum range of the missile and resulted in the engagement of fewer targets. This is logical since a shorter range translates to smaller area of coverage and a reduced number of targets that enter the area that can be targeted.

5.3 Task Force Attack

The Task Force Attack scenario is built on desert terrain and is a Deliberate Attack against a tank battalion at 50% strength. Four scout vehicles conduct a zone reconnaissance from 10-15 kilometers in front of the blue force main body. When the main body is approximately 30 minutes from engaging the tank battalion, the first AH-64D_HFIII Platoon launches. The first AH-64D_HFIII Platoon flies a route in the northern portion of the zone and assumes a battle position between the main body and tank battalion. The second AH-64D_HFIII Platoon launches when the first platoon is in the battle position. After occupying the battle position, the First AH-64D_HFIII Platoon begins the systematic engagement of targets in the northern half of the enemy's defensive position. The second AH-64D_HFIII Platoon flies a similar route as the first platoon and assumes a battle position south of the first platoon. From their battle position, the second AH-64D_HFIII Platoon engages targets in the southern half of the enemy's defensive position. The engagement areas of the AH-64D_HFIII Platoons overlap slightly to ensure full coverage while minimizing target servicing duplication. Tables 19, 20, 21, 22 and 23 contain the pertinent output data from the simulation runs.

Table 19

Normalized Numerical Comparison of Hellfire III Variant Performance for the Task Force Attack Scenario

	Moderate			Adverse		
	MMW	IIR	Ladar	MMW	IIR	Ladar
LER	1.0	1.138	0.925	1.0	0.844	0.953
Hellfire Hits (HH)	1.0	1.054	1.012	1.0	0.784	0.987
HH on Intended Targets	1.0	1.054	1.012	1.0	0.784	0.987
AVR	1.0	1.061	0.973	1.0	0.829	0.986

5.3.1 Practical Significance

The AH-64D_HFIII Platoons provide direct fire from their battle positions and are extremely effective at eliminating enemy vehicles. They engage targets prior to the arrival of the main force. The result is that the blue force main body passes through the tank battalion without suffering any losses. Additionally, the blue force main body only engages targets on rare occasions. During the simulation runs, the mean Hellfire III engagement range was approximately 2/3 of the maximum range; therefore, drift was insignificant. This, coupled with the fact that the enemy vehicles were stationary, precluded the hitting of non-intended targets.

Table 20

Normalized Numerical Comparison of Hellfire Longbow and Hellfire III Variant Performance for the Task Force Attack Scenario

	Moderate				Adverse			
	Longbow	MMW	IIR	Ladar	LongBow	MMW	IIR	Ladar
LER	0.347	1.0	1.138	0.925	0.374	1.0	0.844	0.987
Hellfire Shots	0.422	1.0	1.022	1.010	0.400	1.0	1.024	1.010
Hellfire Kills	0.391	1.0	1.134	0.948	0.417	1.0	0.868	0.995
Helo Losses	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Analysis of Tables 19 and 20 indicates relative parity between the three Hellfire III seekers for all metrics in moderate weather. The indication is that the field of regard size differences between the three Hellfire III seekers are unimportant in determining the outcome of the scenario. There are several peculiarities that require investigation. The first is that Ladar/adverse missile is more effective at killing targets than the IIR/adverse even though the IIR/adverse has a larger field of regard. The data is reasonable since the IIR/adverse has a lower P-hit due to the signature altering effects of weather. The second is that the Ladar/adverse missile performed very well. This was not anticipated since the terminal guidance range of the Ladar seeker is seriously degraded by adverse weather. Due to the range degradation and a minimum "lock on before impact" time requirement, only a small portion of the field of regard is scanned. In ModSAF, the area that is scanned is centered at the drift-altered known target location. Therefore, the missile is

looking where it thinks the target is located, not where the target is actually located. The fact that the Ladar/adverse performed as well as the MMW/adverse indicates that drift was insignificant.

Table 21

MMW Confidence Interval Comparison for Task Force Attack Scenario

	IIR	Ladar	Longbow
LER/MMW/Moderate	Within CI	Within CI	Outside (low) CI
LER/MMW/Adverse	Outside (low) CI	Within CI	Outside (low) CI
HF Hits/MMW/Moderate	Within CI	Within CI	N/A
HF Hits/MMW/Adverse	Outside (low) CI	Within CI	N/A
Intended Tgt/MMW/Moderate	Within CI	Within CI	N/A
Intended Tgt/MMW/Adverse	Outside (low) CI	Within CI	N/A
AVR/MMW/Moderate	Within CI	Within CI	N/A
AVR/MMW/Adverse	Outside (low) CI	Within CI	N/A
HF Shots/MMW/Moderate	Within CI	Within CI	Outside (low) CI
HF Shots/MMW/Adverse	Outside (low) CI	Within CI	Outside (low) CI
HF Kills/MMW/Moderate	Within CI	Within CI	Outside (low) CI
HF Kills/MMW/Adverse	Outside (low) CI	Within CI	Outside (low) CI
Helo Losses/MMW/Moderate	N/A	N/A	N/A
Helo Losses/MMW/Adverse	N/A	N/A	N/A

5.3.2 Statistical Significance

Table 21 indicates that the mean values of the Hellfire III IIR seeker are significantly less than the mean values of the Hellfire III MMW seeker at a 95% confidence interval for all metrics measured in adverse weather conditions. The mean values of the Hellfire III IIR seeker are not significantly different from the mean values of the Hellfire III MMW seeker at a 95% confidence interval for all metrics measured in moderate weather conditions. The mean values of the Hellfire III Ladar seeker are not significantly different from the mean values of the Hellfire III MMW seeker at a 95% confidence interval for all metrics measured in both adverse and moderate weather conditions. The mean values of the Longbow Hellfire missile are significantly less than the mean values of the Hellfire III MMW seeker at a 95% confidence interval for all metrics measured in both moderate and adverse weather conditions.

Table 22

Hellfire III Variant Hypothesis Evaluation

	Result	Reason
LER/Moderate	Null Accepted	Both IIR and Ladar means within MMW CI
LER/Adverse	Null Rejected	IIR mean outside lower boundary of MMW CI
HF Hits/Moderate	Null Accepted	Both IIR and Ladar means within MMW CI
HF Hits/Adverse	Null Rejected	IIR mean outside lower boundary of MMW CI
Hit on intended Target/Moderate	Null Accepted	Both IIR and Ladar means within MMW CI
Hit on intended Target/Adverse	Null Rejected	IIR mean outside lower boundary of MMW CI
AVR/Moderate	Null Accepted	Both IIR and Ladar means within MMW CI
AVR/Adverse	Null Rejected	IIR mean outside lower boundary MMW CI

It can be concluded from Table 22 that the Hellfire III MMW seeker performs better in adverse weather conditions than the Hellfire III IIR seeker. However, differences between the comparison of the Hellfire III MMW seeker and the Hellfire III IIR seeker in moderate weather and the Hellfire III Ladar seeker in both weather conditions cannot be drawn.

Table 23

Hellfire III Variant versus Longbow Hellfire Hypothesis Evaluation

	Result	Reason
LER/Moderate	Null Rejected	Longbow Hellfire mean outside lower boundary of MMW CI
LER/Adverse	Null Rejected	Longbow Hellfire mean outside lower boundary of MMW CI
HF Shots/Moderate	Null Rejected	Longbow Hellfire mean outside lower boundary MMW CI
HF Shots/Adverse	Null Rejected	Longbow Hellfire mean outside lower boundary MMW CI
HF Kills/Moderate	Null Rejected	Longbow Hellfire mean outside lower boundary MMW CI
HF Kills/Adverse	Null Rejected	Longbow Hellfire mean outside lower boundary MMW CI
Helicopter Losses/Moderate	N/A	N/A
Helicopter Losses/Adverse	N/A	N/A

Table 23 indicates that the Longbow Hellfire possess severe performance deficiencies when compared to the three variants of the Hellfire III missile. The Hellfire

shots, Hellfire kills and LER metrics are interrelated and show similar trends. Statistically fewer Longbow Hellfire shots occur than Hellfire III variant shots. Therefore fewer kills result and the Longbow Hellfire LER is less than the Hellfire III variants.

5.4 Deep Attack

The Deep Attack scenario involves the utilization of an Attack Aviation Company to disrupt an enemy Motorized Rifle Division (MRD) prior to an anticipated attack. The AH-64D_HFIII Company uses cover and concealment provided by terrain to penetrate the lead elements and strike the Command, Control, Communication and Intelligence (C4I) elements of the lead MRR. Additionally, the AH-64D_HFIII Company strikes massed armor and attacks targets of opportunity during egress.

Table 24

Normalized Numerical Comparison of Hellfire III Variant Performance for the Deep Attack Scenario

	Moderate			Adverse		
	MMW	IIR	Ladar	MMW	IIR	Ladar
LER	1.0	0.873	1.076	1.0	0.902	0.683
Hellfire Hits (HH)	1.0	0.730	1.025	1.0	0.979	0.813
HH on Intended Targets	1.0	0.724	1.005	1.0	1.009	0.825
AVR	1.0	1.184	1.077	1.0	0.764	0.917

5.4.1 Practical Significance

The AH-64D_HFIII Company is able to penetrate the leading enemy elements and set up battle positions. The extended range capability of the Hellfire III variants enable the placement of the battle positions further from the targets than with the Longbow Hellfire. From the battle positions, the AH-64D_HF III Company can engage a variety of targets at a range that enables them to avoid enemy air defense weapons. The massed enemy units provide a target rich environment. One draw back is that due to the close proximity between vehicles, the Hellfire III variants hit the wrong vehicle on rare occasions. Although it did not happen often, it indicates that some problems may arise with the Hellfire III missiles if the intent is to destroy specific vehicles at ranges that exceed laser spot tracking capability.

Table 25

Normalized Numerical Comparison of Hellfire Longbow and Hellfire III Variant Performance for the Deep Attack Scenario

	Moderate				Adverse			
	Longbow	MMW	IIR	Ladar	LongBow	MMW	IIR	Ladar
LER	0.785	1.0	0.873	1.076	0.526	1.0	0.902	0.683
Hellfire Shots	0.746	1.0	0.732	1.004	0.526	1.0	1.175	0.770
Hellfire Kills	0.785	1.0	0.873	1.076	0.526	1.0	0.902	0.683
Helo Losses	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Tables 24 and 25 show an interesting reversal of the results observed in Table 19 and Table 20. In Tables 19 and 20, the Hellfire III IIR had slighter higher values for the metrics measured in moderate weather than the Hellfire III Ladar. Tables 24 and 25 have slighter higher values for the Hellfire III Ladar than the Hellfire III IIR for all metrics measured in moderate weather. The differences are insignificant when compared to the Hellfire III MMW but show the random variability that is to be expected in a simulation study.

In Table 25 there appears to be a problem concerning the LER mean value for the IIR/adverse. Based on the analysis of the seekers and the output from the TF Attack and TF Defense scenarios, the expected results is that LER mean value for the IIR/adverse will be significantly less than the MMW/adverse. However, the two means vary by only 9.8%. Further inspection of Table 25 reveals that the probable justification is that 17.5% more Hellfire III IIR missiles were fired than Hellfire III MMW during the simulation runs. Looking at Table 24 it is apparent that despite a degraded probability of hit due to the adverse weather, the 17.5% of additional missile launches offset the reduced performance capability. Therefore, it can be concluded that the results are skewed but consistent with the results observed in the TF Attack and TF Defense scenarios.

The Ladar/adverse column of Table 25 is disconcerting and appears to be a direct contradiction of the results of the TF Attack scenario listed in Table 20. However, closer inspection once again reveals that the proximate cause of the erratic table entry is the number of Hellfire III Ladar missiles that were launched during the adverse weather runs. For some undetermined reason, 23% fewer Hellfire III Ladar missiles were launched than Hellfire III MMW during the running of the adverse scenarios. Since nothing in the

computer code alters the launching decision of the Hellfire III missile variants with respect to seeker and weather conditions, it is reasonable to expect that the hell fire shots metric should be approximately 1.0 for all Hellfire III variants.

Table 26

Confidence Interval Comparison for Deep Attack Scenario

	IIR	Ladar	Longbow
LER/MMW/Moderate	Within CI	Within CI	Outside (low) CI
LER/MMW/Adverse	Within CI	Outside (low) CI	Outside (low) CI
HF Hits/MMW/Moderate	Within CI	Within CI	N/A
HF Hits/MMW/Adverse	Within CI	Within CI	N/A
Intended Tgt/MMW/Moderate	Within CI	Within CI	N/A
Intended Tgt/MMW/Adverse	Within CI	Within CI	N/A
AVR/MMW/Moderate	Outside (high) CI	Within CI	N/A
AVR/MMW/Adverse	Outside (low) CI	Within CI	N/A
HF Shots/MMW/Moderate	Outside (low) CI	Within CI	Outside (low) CI
HF Shots/MMW/Adverse	Outside (high) CI	Within CI	Outside (low) CI
HF Kills/MMW/Moderate	Within CI	Within CI	Outside (low) CI
HF Kills/MMW/Adverse	Within CI	Outside (low) CI	Outside (low) CI
Helo Losses/MMW/Moderate	N/A	N/A	N/A
Helo Losses/MMW/Adverse	N/A	N/A	N/A

5.4.2 Statistical Significance

The deviations in the number of Hellfire III IIR and Ladar missiles (Table 25) as discussed in section 5.4.1 have influenced the outcome of the confidence interval comparisons. The Hellfire III IIR missile's LER mean value is within the Hellfire III MMW confidence interval (Table 26) because 17.5% more were fired than Hellfire III MMW which resulted in only 9.8% fewer kills being recorded (Table 25). Also, since 23% fewer Hellfire III Ladar missiles (Table 25) were fired in the adverse weather scenarios, the LER mean value for the Hellfire III Ladar fell below the 95% confidence interval (Table 26).

Table 27
Hellfire III Variant Hypothesis Evaluation

	Result	Reason
LER/Moderate	Null Accepted	Both IIR and Ladar means within MMW CI
LER/Adverse	Null Rejected	Ladar mean outside lower boundary of MMW CI
HF Hits/Moderate	Null Accepted	Both IIR and Ladar means within MMW CI
HF Hits/Adverse	Null Accepted	Both IIR and Ladar means within MMW CI
Hit on intended Target/Moderate	Null Accepted	Both IIR and Ladar means within MMW CI
Hit on intended Target/Adverse	Null Accepted	Both IIR and Ladar means within MMW CI
AVR/Moderate	Null Rejected	IIR mean outside upper boundary of MMW CI
AVR/Adverse	Null Rejected	IIR mean outside lower boundary of MMW CI

Entries in Table 27 indicate that there is parity between the three Hellfire III seeker variants when compared against one another using the moderate weather mean values for the LER, Hellfire hits and Hellfire hits on intended target metrics. The AVR/Adverse row entries further convolute the understanding of the reasons why the LER mean value of the IIR/adverse missile was within the .95 confidence internal. The AVR is a measure of how fairly damage was assessed. A low AVR indicates that the damage assessments were not severe. A high AVR indicates that mostly mobility and firepower or catastrophic kills were assessed. Since the AVR/Adverse row indicates that the mean value of the Hellfire III IIR missile fell below the lower limit of the 95% confidence interval, it is reasonable to assume that few mobility and firepower or catastrophic kills were assessed. However, this does not appear logical knowing that the mean value of the LER metric for the IIR/adverse was within the 95% confidence interval. Based on this analysis, the raw and pre-normalized data were reviewed. Closer inspection of the raw data revealed that a few runs with large observed values skewed the mean value to the right. Analysis of the pre-normalized data indicates that the mean value for the IIR/adverse is in the confidence interval, but it was near the lower limit. If a few more runs were conducted, the value may drop below the lower bound.

Table 28

Hellfire III Variant versus Longbow Hellfire Hypothesis Evaluation

	Result	Reason
LER/Moderate	Null Rejected	Longbow Hellfire mean outside lower boundary of MMW CI
LER/Adverse	Null Rejected	Longbow Hellfire mean outside lower boundary of MMW CI
HF Shots/Moderate	Null Rejected	Longbow Hellfire mean outside lower boundary of MMW CI
HF Shots/Adverse	Null Rejected	Longbow Hellfire mean outside lower boundary of MMW CI
HF Kills/Moderate	Null Rejected	Longbow Hellfire mean outside lower boundary of MMW CI
HF Kills/Adverse	Null Rejected	Longbow Hellfire mean outside lower boundary of MMW CI
Helicopter Losses/Moderate	N/A	N/A
Helicopter Losses/Adverse	N/A	N/A

Table 28 shows the same trends that were illuminated in the analysis of the TF Attack and TF Defense scenarios. The Hellfire III missile variants are superior to the Longbow Hellfire even though the Hellfire III MMW and Longbow Hellfire have the same seeker performance. However, a significant difference exists in the maximum range capability and the methods by which they are replicated in ModSAF. The Hellfire III MMW is replicated using the AMETA algorithm while the Longbow is replicated through the use of the standard Libbalgun targeting process.

5.5 Data Analysis Summary

The multi-variant analysis seems to indicate that there is no statistical significance between the Hellfire III MMW/adverse and the Hellfire III Ladar/adverse. This is not logical and indicates that the level of granularity within the currently developed model is not adequate for multi-variant analysis. The data could be further skewed by the limited number of runs that were performed during the data collection phase of the research. On average, 10 runs were completed for each seeker/weather combination of each scenario. The accomplishment of 30 production runs for each seeker/weather combination for each of the scenarios may have a significant impact on the results.

One of the observations noted during the analysis is that the effects of drift are minimal. Drift does not usually cause a target miss or a hit to occur on a vehicle that was not the intended target, but when it does, it is because the target vehicle and the hit vehicle are closely located. In the Deep Attack scenario, several vehicles that were not the intended target were hit by Hellfire missiles. This is reasonable since the vehicles were in assembly areas waiting to begin an attack. Also, several vehicles that were not the intended target were hit by Hellfire missiles during the Task Force Defense scenario. The result is logical and due to the intended target moving away from the drift adjusted aimpoint and the unintended target moving toward the drift adjusted aimpoint while the Hellfire missile was in flight.

A second observation is the reluctance of the ground forces to engage one another. BlueFOR and RedFOR units would not fight unless they were located within a hundred meters. The result is that the LER is primarily a reflection of the Hellfire missile engagements. The ground units may have not engaged each other due to an inability to

see one another caused by the use of the –allow_env command at scenario start-up. The use of the –allow_env command in the ModSAF execution script may have resulted in the units experiencing severely degraded weapon system visual capabilities. A similar problem was noted during the validation process when it was discovered that even in moderate weather, the RedFOR moved very slowly (3 km per hour) when the –allow_env command was used. Corrections were implemented that restored the drivers capability and resulted in normal traveling speeds. Although the ground forces did not fight, it was not considered a hindrance to the research since the focus was on the evaluation of Hellfire III missile variants, performance comparison of the Hellfire III missiles variants to the Longbow Hellfire and the validation of the AMETA algorithm.

A third observation is that a visual replay tool is essential for eliminating improbable occurrences. The rapid reviewing of data files facilitated the identification of undesirable events and subsequent elimination of runs that were invalid. The runs that were eliminated contained events associated with the helicopters that influenced the evaluation of the Hellfire missiles. On several runs the helicopter behaviors were erratic due to computational demands placed on the processor. The outcome was a variety of problems which included suspended operations (died in flight without enemy action), starburst flight paths, and complete disregard for assigned missions. If a helicopter platoon experienced an improbable occurrence, the simulation run was eliminated.

CHAPTER 6

CONCLUSION

6.1 Significance of the Research

This research details an extension of ModSAF known as the Accumulated Missile Error and Target Action (AMETA) algorithm and proves the viability of the extension. The AMETA method facilitates realistic replication of advanced air-to-ground precision guided munitions in constructive simulations. The AMETA algorithm is built upon a foundation of discrete event simulation principles. The AMETA algorithm uses decision points along a missiles normal flight profile to apply accumulated errors and achieve realistic in-flight outcomes without the need to perform computationally expensive flight path projections. The decision points are situated at the end of events where the accumulated errors would normally be realized. Using this concept, any quantifiable error can be applied to the flight of a missile represented in a constructive simulation.

The AMETA algorithm was validated through a validation process that relied on expert analysis prior to being used to evaluate the performance of three Hellfire III variants and the Longbow Hellfire missile. During the performance evaluation, the three Hellfire III variants were compared to one another using four metrics and then compared to the Longbow Hellfire using three additional metrics. The LER metric was common to both of the performance evaluations. Therefore, four metrics were used to compare the

Hellfire III variants and four metrics were used to compare the Hellfire III variants to the Longbow Hellfire with the LER being common between the two comparisons.

Given that this was a demonstration with a number of issues, analysis of the output data from the simulation runs indicates that there is no discernable performance difference between the three Hellfire III variants in moderate weather. There is also no statistical evidence that a difference exists between the Hellfire III MMW and Hellfire III Ladar when employed in adverse weather conditions. However, the Hellfire III MMW does perform better than the Hellfire III IIR in adverse weather conditions. Additional analysis indicates a significant difference between the performance of the Longbow Hellfire missile and the Hellfire III missile variants. Despite have similar target acquisition and probability of hit capabilities as the Hellfire III MMW, the mean values of the metrics measured using the Longbow Hellfire were significantly below the lower bound of the 95% confidence intervals developed using the Hellfire III MMW variant as the baseline.

The fundamental logic behind the AMETA algorithm is solid. However, some concern exist that the algorithm does not seem to provide enough detail with which to make an analysis of multiple variants. Therefore, deeper research must be conducted to identify subtle difference between the seekers being evaluated and the identification of metrics that enable more precise measurements. Additionally, the computer code requires refinement to allow the representation of the subtle performance differences between the seekers. Based on initial analysis of the seekers, the output should have indicated a difference between the Hellfire III MMW/adverse and the Hellfire III

Ladar/adverse. The absence of the difference indicates that future work must be accomplished if the AMETA algorithm is to be used for multi-variant analysis.

6.2 Areas for Further Research

Numerous errors associated with the detection of a target, computation of firing data and target hand-off are not considered in the AMETA method. This is due to the lack of valid data concerning these factors. However, if the factors can be quantified, they can be considered in the algorithm. This is accomplished by adding the errors at a discrete point during the flight of the missile where they would normally be realized and adjusting the missile's position and behavior based on the errors.

Future studies can identify the potential magnitude of Target Location Errors (TLE) by analyzing the capabilities of the intelligence gathering devices and identifying the normal target processing times. The TLE would have both a time independent and time dependent components. The time independent component is a direct reflection of the capabilities of the detecting model to accurately locate the target. The time dependent component is depended upon a sum of the time to process a target and the time of flight of the missile from the launch point to the target location. Data latency errors increase as the time interval between target detection and missile launch increases and add to the initial target location area.

A simple table, such as Table 29, can be used to determine a compensated aimpoint based on the elapsed time from detection to missile impact and the target velocity. The accumulated distance entries were computed by first expressing the target's velocity in meters per second and then multiply that rate by the assumed elapsed

time from detection to missile impact. The determined table value must then be added to the time independent error to determine a TLE. The TLE could then be applied to the location of the target at the time of detection. A new offset aimpoint would then be identified based on the TLE and the direction of movement of the target at the time of detection.

Table 29

Target Movement Based on Elapsed Time and Velocity

Elapsed Time (Seconds)	Target Velocity (km/hr and Meters/Sec) 15 km/hr 4.2 meters/sec	20 km/hr 5.6 meters/sec	25 km/hr 6.9 meters/sec	30 km/hr 8.3 meters/sec
45	189	252	315	374
50	210	280	345	415
55	231	308	380	457
60	252	336	415	498
65	273	364	450	540

Relative geometry errors are a result of the launching platform not knowing the precise location of itself and the location of the target. They result in computational errors since an accurate firing solution is impossible if the start and end points are not precisely known. These errors could be compensated through the use of a random draw to determine the amount of error to be applied. This procedure would require the identification of a mean error and a standard deviation associated with the error as well as reliance on the empirical rule. Using the empirical rule, it is safe to assume that 68% of

all occurrences would fall +/- 1 standard deviation from the mean. 95% of all occurrences will be within 2 standard deviations of the mean and nearly all occurrences will be within 3 standard deviations of the mean. Therefore, every time a missile is fired, a random draw is performed on a range of numbers from 0 to 99. If the number is between 1 and 68, a 1 standard deviation error is assessed. If the number is between 69 and 95, a 2 standard deviation error is assessed.

In addition to accounting for errors, the level of seeker representation can be refined. The present AMETA algorithm does not delve into the minute details of the seeker scanning patterns. It assumes that the field of regard will be scanned in a specific amount of time at regular intervals. This is represented by looking at the field of regard as a single snapshot. In actuality, the field of regard is scanned in a pattern and the entire field of regard is not seen as a singular unit. The seeker performs a systematic scanning pattern that allows the entire field of regard to be viewed over the period of time required to complete the scan. Also, the three seekers do not have the same scanning procedures. The MMW seeker scans with a lateral swipe, the Ladar seeker uses a zigzagged lateral pattern and the IIR seeker uses lateral sequential frames. All three seekers begin their scans at the closest edge of the field of regard and end at the farthest edge.

The facts discussed above have implications on the effectiveness of the seekers with respect to the various locations of targets within a field of regard. If a target is located in a portion of a field of regard, it may be seen by one seeker and not the others due to the scanning pattern, weather conditions and the velocity of the missile. Also, a target may be seen too late for the missile to make adequate flight adjustments. Therefore, a realistic and computationally efficient method of dividing the field of regard

must be devised to accurately replicate the missile's behavior in the constructive model. Three possible solutions exist and are shown in Figure 13. All three options involve dividing the field of regard into thirds since it takes approximately 3 seconds for a seeker to view the entire field of regard. The regions are scanned sequentially to ensure full coverage of the field of regard.

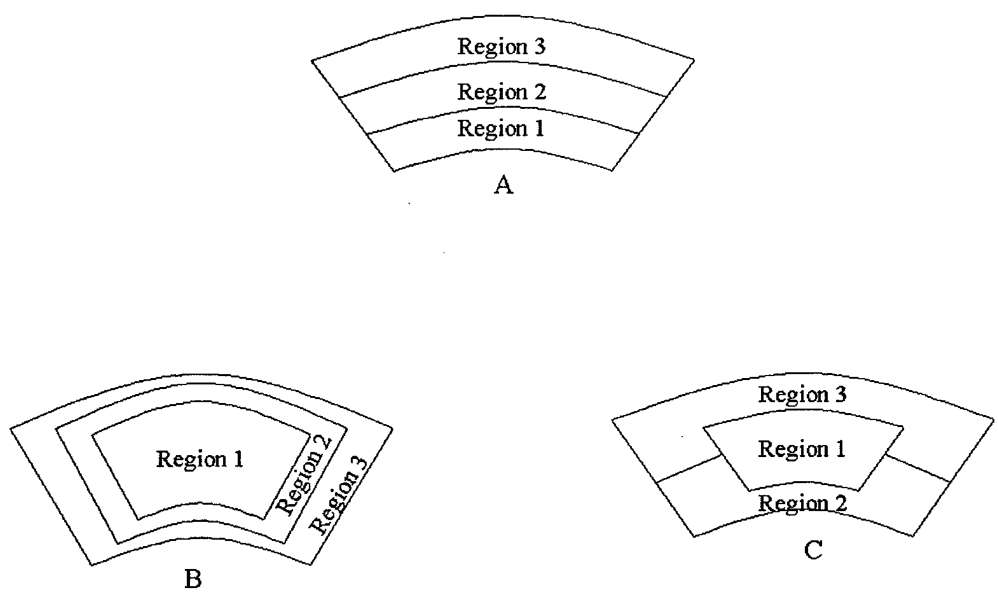

Figure 14: Field of Regard Coverage Concepts

The size of the regions in Concept A can be determined by determining the total length of the field of regard and dividing by 3. The regions in Concept B are defined by first determining the center of the field of regard and then computing the 1/3, 2/3 and 3/3

regions of the field of regard. The regions of Concept C is more difficult to compute and requires a combination of the methods used to determine the region size in Concept A and Concept B. Region 1 of Concept C is determined by computing 1/3 of the field of regard and centering the region on the center point of the field of regard. Regions 2 and 3 are each ½ of the total field of regard minus ½ of region 1.

The tactics, techniques and procedures for tactical employment of an improved Hellfire missile is another area of possible research. During the process of this research, careful consideration was given to the potential skewing of data based on the employment of the missiles. As a precaution, the three-scenario concept was devised. Once a scenario was validated, the unit taskings and locations did not change. Future research could be based on any of the scenarios and involve a variety of unit taskings and locations. The research could answer questions concerning force mix, weapons loads, battle position selection and the viability of ground launched Hellfire missiles. The research could also attempt to determine the best employment technique for engaging stationary and moving targets. One aspect of the missiles noted during the research is that the width of the field of regard is generally greater than the length of the field of regard. This implies that missile performance from a side aspect will be greater than missile performance from a straight on aspect. In conjunction with this research, refinements to the seeker and missile behaviors could be investigated to determine the optimal size of fields of regard and scanning patterns.

The hypotheses would have to be expanded to support the investigation into the optimal tactics, techniques and procedures of employment. The Reaper would also require modification so that the essential information can be acquired. By filtering out

more information, the holes in the sieve are being reduced and the reasons associated with the outcome observations can be refined. The expanded hypotheses are listed in Table 30. The adverse weather/moving or stationary hypotheses are grouped together based on the anticipated results that were presented in Section 4.3.

Table 30

Modified Hellfire III Comparison Hypotheses

	Adverse Weather Moving/Stationary	Moderate Weather Stationary	Moderate Weather Moving
Loss Exchange Ratio (LER)	H_0: MMW $\bar{y}$ = IIR $\bar{y}$ = Ladar $\bar{y}$	H_0: MMW $\bar{y}$ = IIR $\bar{y}$ = Ladar $\bar{y}$	H_0: MMW $\bar{y}$ = IIR $\bar{y}$ = Ladar $\bar{y}$
	H_A: MMW $\bar{y}$ > IIR $\bar{y}$ > Ladar $\bar{y}$	H_A: MMW $\bar{y}$ < IIR $\bar{y}$ > Ladar $\bar{y}$	H_A: MMW $\bar{y}$ > IIR $\bar{y}$ ≠ Ladar $\bar{y}$
Hellfire Hits	H_0: MMW $\bar{y}$ = IIR $\bar{y}$ = Ladar $\bar{y}$	H_0: MMW $\bar{y}$ = IIR $\bar{y}$ = Ladar $\bar{y}$	H_0: MMW $\bar{y}$ = IIR $\bar{y}$ = Ladar $\bar{y}$
	H_A: MMW $\bar{y}$ > IIR $\bar{y}$ > Ladar $\bar{y}$	H_A: MMW $\bar{y}$ < IIR $\bar{y}$ > Ladar $\bar{y}$	H_A: MMW $\bar{y}$ > IIR $\bar{y}$ ≠ Ladar $\bar{y}$
Hellfire Hits on Intended Target	H_0: MMW $\bar{y}$ = IIR $\bar{y}$ = Ladar $\bar{y}$	H_0: MMW $\bar{y}$ = IIR $\bar{y}$ = Ladar $\bar{y}$	H_0: MMW $\bar{y}$ = IIR $\bar{y}$ = Ladar $\bar{y}$
	H_A: MMW $\bar{y}$ > IIR $\bar{y}$ > Ladar $\bar{y}$	H_A: MMW $\bar{y}$ < IIR $\bar{y}$ > Ladar $\bar{y}$	H_A: MMW $\bar{y}$ > IIR $\bar{y}$ ≠ Ladar $\bar{y}$
Assessed value Ratio (AVR)	H_0: MMW $\bar{y}$ = IIR $\bar{y}$ = Ladar $\bar{y}$	H_0: MMW $\bar{y}$ = IIR $\bar{y}$ = Ladar $\bar{y}$	H_0: MMW $\bar{y}$ = IIR $\bar{y}$ = Ladar $\bar{y}$
	H_A: MMW $\bar{y}$ > IIR $\bar{y}$ > Ladar $\bar{y}$	H_A: MMW $\bar{y}$ < IIR $\bar{y}$ > Ladar $\bar{y}$	H_A: MMW $\bar{y}$ > IIR $\bar{y}$ ≠ Ladar $\bar{y}$

The Assessed Value Ratio (AVR) was created during this research to assist in the exploration of causative factors. It could be redefined for future research to possibly assist in the determination of the importance of other variables. One such possibility is to

define the AVR similar to the LER as a ratio between Red Force losses and Blue Force losses. A large AVR would indicate good blue force performance. The equation is:

$$\text{AVR} = \frac{\text{Red Force Losses Total Point Tally}}{\text{Blue Force Losses Total Point Tally}} \tag{12}$$

Using the new AVR, the contribution of each missile variant to the success of the Blue Forces during each scenario run can be assessed. This is accomplished by identifying the damage caused by the advanced air-to-ground missile and removing it from the Red Force Total Point Tally (RFTPT). The result is contribution of the ground force to the success of the battle and allows us to compare runs with and without advanced air-to-ground missiles. It is assumed that scenarios that result in greater RedFOR losses due to advanced air-to-ground missiles will also result in greater RedFOR losses due to Blue Ground Forces. This is because the Blue Ground Forces will have a force ratio advantage over the red force and therefore will be able to inflict heavier damage.

The NETMOSA methodology was devised and implemented to facilitate this research. However, it is still in its infancy and is not yet proven. Future research could focus on the NETMOSA methodology to determine if it is a unique, effective and efficient method of determining new system requirements. Research in this area would require a comprehensive knowledge of the procurement process and significant involvement by experts working in the field of system acquisition.

6.3 Lessons Learned

The lessons learned during this research are the same lessons that have been documented by other researchers. In their book, *Simulation Modeling and Analysis,* Averill M. Law and W. David Kelton identify steps of a simulation study. it can be safely assumed that the steps are result of lessons learned. The steps are:

1. Formulate problem and plan the study
2. Collect data and define a model
3. Check model for validity
4. Construct a computer program and verify
5. Make pilot runs
6. Check pilot runs for validity
7. Design experiments
8. Make production runs
9. Analyze output data
10. Document, present and implement results

Although this research was conducted with these steps as a guide, the true value of the steps did not become evident until mistakes were made or problems arose. Each step must be performed correctly, not just receive cursory attention. The importance of a solid problem statement and a well defined scope cannot be overstated. Additionally, validity checks are essential to ensure that hidden problems do not evolve as the research progresses. Care must be taken so that the data gathered from the research is worthy of analysis. Mistakes might be made during the analysis of the data, and if they are, they

should at least be made when evaluating the significance of valid data. The final step of documenting and presenting the data is sometimes minimized. Documentation should be a continuous process that is performed concurrently with the research. Accurate and timely recording of significant events that occur during the research process aides in the completion of this step by helping to preserve the validity of the data and providing time to consider the significance of the data. Rumination during the process increases the sophistication and information conveying capability of the documentation. Relationships between the elements of the data can be developed and the links can be articulated for posterity.

APPENDIX A

Hellfire III Probability of Hit Tables

```
;; This is for the MMW Hellfire III, Moving and stationary targets, good and bad weather.
;;
;; File created 8 September 98 by Jim brashear
:: Hit_vs_Range

;; Munition Name            Velocity Threshold          INU Drift
(US_HellfireIII_MMW               ##.#               #.###    #.###

; Seeker data     HFOV      VFOV      Look down   Range_70%   Range_20%   altitude
; moving          #.##      #.##      #.##        ####        ####        ####
; stationary      #.##      #.##      #.##        ####        ####        ####

;;Table body
( #####        .##         .##         .##         .## )
( #####        .##         .##         .##         .## )
( #####        .##         .##         .##         .## )
( #####        .##         .##         .##         .## )
( #####        .##         .##         .##         .## )
( #####        .##         .##         .##         .## )
( #####        .##         .##         .##         .## )
( #####        .##         .##         .##         .## )
( #####        .##         .##         .##         .## )

;;Top Line:
      ;1) Name of the munition as described in common/libsrc/libprotocol/mun_type.cdf
      ;2) The velocity threshold to discriminate between moving and stationary targets
      ;3) The standard deviation of the time dependent drift for the INU measured in degrees per second
      ;4) The standard deviation of the time independent drift for the INU measured in degrees

;;Seeker Data
      ;1.a) HFOV: Footprint azimuth for moving targets measured in degrees
      ;1.b) VFOV Footprint elevation for moving targets measured in degrees
      ;1.c) look down: look down angle for moving targets measured in degrees
      ;1.d) range_70%: Max length (meters) of terminal guidance range for 70% day
      :1.e) range_20%: Max length (meters) of terminal guidance range for 20% day
      ;2.a) HFOV: Footprint azimuth for stationary targets measured in degrees
      ;2.b) VFOV Footprint elevation for stationary targets measured in degrees
      ;2.c) look down: look down angle for stationary targets measured in degrees
      ;2.d) range_70%: Max length (meters) of terminal guidance range for 70% day
      :2.e) range_20%: Max length (meters) of terminal guidance range for 20% day


;;Table Body
;;column 1 is length (meters) of terminal guidance phase
;;column 2 is the good weather, stationary target probability of hit
;;column 3 is the bad weather, stationary target probability of hit
;;column 4 is the good weather, moving target probability of hit
;;column 5 is the bad weather, moving target probability of hit
;;***P-hit includes P-hit and P-acq
```

Appendix B

Simulation Run Batch Script

```
#!/usr/bin/sh
rm ../../data_collection/data_file.*
rm ../../data_collection/data_file_new.*

cp ../../libsrc/libattrdb/ attrdb_MMW.rdr ../../data/attrdb.rdr
cp ../../libsrc/libenvinit/envinit_70.rdr ../../data/envinit.rdr

for I in 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
do
Modsaf_sgi_6_2 -nonet -terrain  knox-0311 -version4 -sourcefile HellfireIII -nogui
mv ../../data_collection/data_file.1 ~/$hoss/data/     $I
Echo "Hellfire_III_Knox_MMW_70%" $I


cp ../../libsrc/libattrdb/ attrdb_MMW.rdr ../../data/attrdb.rdr
cp ../../libsrc/libenvinit/envinit_20.rdr ../../data/envinit.rdr

for I in 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
do
Modsaf_sgi_6_2 -nonet -terrain  knox-0311 -version4 -sourcefile HellfireIII -nogui
mv ../../data_collection/data_file.1 ~/$hoss/data/     $I
Echo "Hellfire_III_Knox_MMW_20%" $I


cp ../../libsrc/libattrdb/ attrdb_IIR.rdr ../../data/attrdb.rdr
cp ../../libsrc/libenvinit/envinit_70.rdr ../../data/envinit.rdr

for I in 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
do
Modsaf_sgi_6_2 -nonet -terrain  knox-0311 -version4 -sourcefile HellfireIII -nogui
mv ../../data_collection/data_file.1 ~/$hoss/data/     $I
Echo "Hellfire_III_Knox_IIR_70%" $I


        done
        done_time = 'date'
        echo "start time : "$start_time
        echo "end time : "$done_time
```

LIST OF REFERENCES

Alford, Jonathan, *The Impact of new Military Technology,* The international Institute for Strategic Studies, Gower publishing Company, 1984.

Antoniotti, Joseph C., *Precision-guided Munitions, Semi-active laser versus millimeter-wave guidance,* International Defense Review, V19, N9, 1986, pages 1269-1276.

Canada, John R. and Sullivan, William G., *Economic and Multiattribute Evaluation of Advanced Manufacturing Systems,* Prentice Hall, Englewood Cliffs, New Jersey, 1989.

Clark, Asa A. and Lilley, John F., *Defense Technology,* New York: Praeger Publishers, 1989.

Craft, Michael A. and Karr, Clark R., *Testing Future weapon systems Using CGF Systems,* IST-TR-96-18 pages 141-150, July 23-25 1996 Orlando FL.

Dargan, John L., *Autonomous Weapon Guidance,* Wright Laboratory, Armament Directorate, Eglin Air Force Base, September 1993.

Daskal, Steven e., "A Hot Issue: Infra-red Sensors and Infra-red Countermeasures", *Military Technology,* Vol. XIV, issue 9, 1990, pages 97-105.

Dereniak, E.L. and Boreman, G.D., *Infrared Detectors and Systems,* John Wiley and Sons, New York, New York, 1996.

Eichblatt, E.J. and Pignatro, A., *Guided Missile Testing,* Progress in Astronautics and Aeronautics, V:119, 1989.

Frieden, David R., *Principles of Naval Weapons Systems,* Naval Institute Press, Annapolis, Maryland, 1985.

Friedman, George and Friedman, Meredith. *The Future of War*, New York: Crown Publishers, 1996.

Holst, Gerald C., *Electro-Optical Imaging System Performance,* JCD Publishing, Winter Park Fl, 1995.

Jane's Air launched Weapons. *Air-to Surface missiles,* Thomson Publishing, issue 26, March 1997.

Keller, John, *Will Ladar be the Next DOD's Quantum Leap?* Military & Aerospace Electronics, pages 25-27, March 15, 1993.

Kotchman, Donald P. and Glasgow, Wesley L., *Applying Modeling and Simulation to the Grizzly Program,* Army RD&A, January-February 1998, PB 70-98-1, pages 30-33.

Loral, *ModSAF Software Architecture Design and Overview Document,* DTIC Document AD-A282 740, Aug 1994.

Mendenhall, William and Sincich, Terry, *Statistics for Engineering and the Sciences,* Prentice Hall, Upper Saddle River, New Jersey, 1995.

Richard, V.W., *Millimeter Wave Radar Applications to Weapon Systems,* Millimeter Wave Radar, Artech House, Dedham, MA, 1980.

Richardson, Doug. "Laser-Guided Munitions", *Jane's 1981-82 Military Annual*, pages 77-87.

Stargardt, Clifton D., *Quantification of Weather Effects on Imaging Laser Radar,* DTIC Document ADA323224, March 1997.

Sundaram, G.S., *Millimeter Waves - The much awaited Technological Breakthrough?,* International Defense Review, V 11, N 2, Feb. 1979, pages 271-277.

Teal group Corporation, "AGM-114 Hellfire", *World Missile Briefing*, Teal Group, November 1997.

Ullom, Larry and Fischer, Peter, *Using an Ordnance Server to provide Validated Weapons Models to ModSAF,* DTIC Document ADA314020, 14 June 1996.

Walker, J.R, *Weapons and Warfare, Conventional Weapons and Their Roles in Battle,* New York: Brassey Defense Publications, 1987.

Williams, Jon, *Introduction to ModSAF 4.0,* Institute for Simulation and Training, University of Central Florida, Orlando, Fl, 1999.